CHAPTER 2 SETTING

2.1 Location

The NODOS Project is located in the Coast Range foothills and lowlands along the western edge of the northern Sacramento Valley (Figure 2-1). The United States Geological Survey (USGS) watersheds and subbasins containing the proposed off-stream reservoir include Lower Grapevine, Funks, Howard, Upper Grapevine, Antelope, Upper and Lower Hunters Creeks, and McDowell Canyon.

The key feature of the NODOS Project, the proposed Sites Reservoir, is located in north-central Colusa County and south-central Glenn County, approximately 10 miles west of the community of Maxwell. Two reservoirs are under consideration at the same site, one with a maximum capacity of 1.81 MAF inundating approximately 14,000 acres, the other with a maximum capacity of 1.27 MAF inundating an area of approximately 12,500 acres. The proposed reservoir inundation areas include most of Antelope Valley and the small community of Sites. The reservoir is in the Funks Creek and Stone Corral Creek watersheds and includes the eight associated USGS subbasins.

2.2 Topography

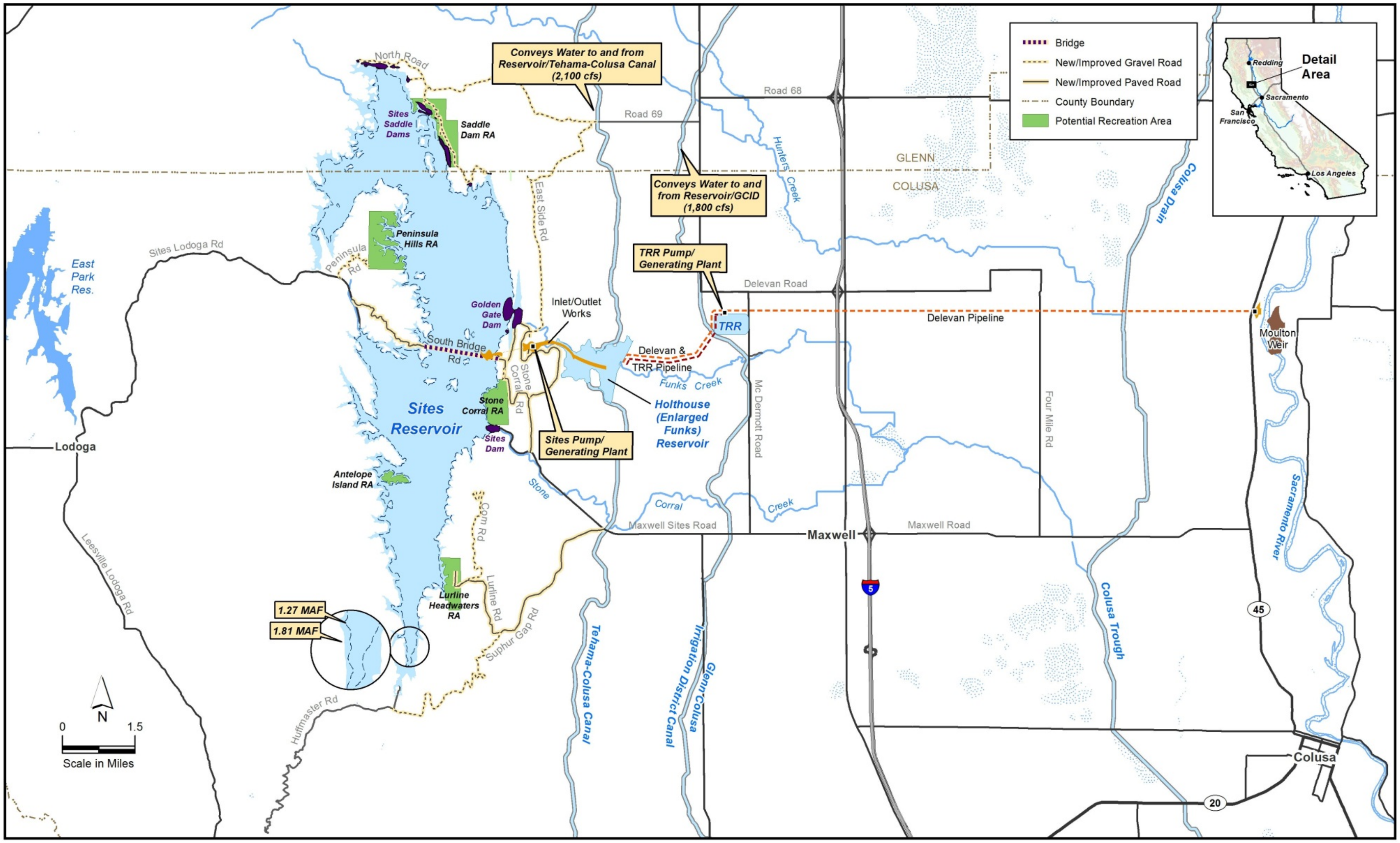
The physical topography of the watersheds draining the east side of the Coast Range toward the Sacramento Valley is diverse. The topography ranges from steep, rugged, mountainous terrain within the upper watersheds to rolling foothills in the project area, to relatively flat alluvial terrain as the watersheds enter the Sacramento Valley. Elevations range from less than 40 feet on the valley floor to more than 8,000 feet along the Coast Range divide.

The proposed Sites Reservoir would be situated between the Sacramento Valley to the east and the mountainous portion of the Coast Range on the west. The Coast Range Mountains are a series of rugged, north-south trending ridges dissected by narrow canyons containing steep gradients, and entrenched streams. A relatively narrow band of steep rolling foothills, approximately 2 to 3 miles wide, separates the proposed reservoir area from the Sacramento Valley. Antelope Valley, the primary inundation area of the proposed Sites Reservoir, lies between this narrow band of foothills and the more mountainous Coast Range. This relatively narrow north-south trending valley is approximately 13 miles long and up to 2 miles wide. Elevation of the Antelope Valley floor ranges from 320 to 400 feet above mean sea level (msl), while the foothills separating the valley from the Sacramento Valley reach a maximum elevation of 1,300 feet. Elevations along the west side of Antelope Valley increase rapidly with several peaks within 2 miles of the valley margin above 2,000 feet.

2.3 Climate

The climate of the watersheds draining into the western Sacramento Valley is typical Mediterranean. Winters are rainy and relatively mild with only occasional freezing temperatures at the lower elevations; summers are comparatively dry and hot.

Figure 2-1. Sites Reservoir Project – Location Map



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The rainy season normally begins in September and continues through March or April. Rains may continue for several days at a time, but are usually gentle. Summer rains are rare, as are thunderstorms and hailstorms. Thunderstorms occur approximately 10 days per year in the Sacramento Valley, occasionally producing high-intensity rainfall of short duration. Most precipitation is associated with migrant storms that move across the area during winter. Snow is the dominant form of precipitation above 5,000-foot elevations and persists on north- and east-facing slopes into the early summer.

High temperatures occur during July, August, and September, with temperature readings commonly in excess of 100 degrees Fahrenheit (ºF). Fog of varying density and duration is common within the Sacramento Valley during winter. However, due to the physical topography, dense or persistent fog is much less common in the project areas. Winds occur seasonally, with dry, north winds common during the summer and fall, while winds from the south are frequently associated with winter storm events. Winds in excess of 60 miles per hour (mph) may occur; however, these events are relatively uncommon and of short duration. Average wind speed at Red Bluff is 8.8 mph, with the strongest winds reported during the winter months. Gross evaporation, the depth of water lost to the atmosphere, averages approximately 70 inches per year in the foothill region.

2.4 Vegetation

Approximately 92 percent of the proposed Sites Reservoir inundation area is annual grassland community with the remaining areas dominated by blue oak woodland and small amounts of chaparral, riparian wetlands, cultivated grain, and non-vegetated areas. The blue oak woodland gives way to Foothill pines above the crest elevations of the two principal dams and large chaparral stands emerge on the southern exposures and shallow soils above the dam crest elevations.

2.5 Watershed Hydrology

The watershed contributing inflow directly to Sites Reservoir drains approximately 83 square miles. Average annual precipitation within the basin is approximately 19 inches (Sites Reservoir PMF Report) and occurs almost exclusively in the form of rain. Snowfall is not common below 5,000 feet elevation. Snow does occur annually at the higher elevations in the coastal range. Some areas within western Glenn County frequently receive between 60 and 75 inches of precipitation per year, primarily in the form of snow.

Streams draining into the proposed reservoir are ephemeral with little or no flow from July to October. However, these streams tend to respond rapidly to significant rainfall events. Flash flooding with substantial overland flow has been observed. Flow recorded at the stream gauge on Stone Corral Creek near Sites is representative of the flow variability of these small ephemeral streams. Annual discharge varied from 0 AF in 1972, 1976, and 1977 to 39,930 AF in 1963, and averaged 6,500 AF. Monthly volumes in excess of 15,000 AF have been documented.

2.5.1 Funks Creek

Funks Creek has 43 square miles of drainage area. No stream gauge currently exists on Funks Creek, and no accurate estimate of 100-year discharge is available. However, as the topography and soil composition of the watershed are similar to those of Stone Corral Creek, where stream flow records are available, and given the comparable drainage areas of the two watersheds, it may be reasonably assumed that the 100-year discharge into Funks Creek would be similar to that of Stone Corral Creek.

2.5.2 Stone Corral Creek

The drainage area of the Stone Corral Creek watershed is 38.2 square miles. The 100-year discharge was established in a 1987 Department of Water Resources (DWR) Colusa Basin flood flow frequency analysis at 7,870 cfs (March 10, 1987, Colusa Basin Flood Flow Frequency Analysis). This value was based on 25 years of discharge measurements collected near the town of Sites, with interruption, from 1958 through 1985.

2.6 Flood Hydrology

2.6.1 Flood Inflows and Volumes

A probable maximum flood (PMF) analysis for the Sites Reservoir watershed was performed to determine the performance of the reservoir in response to inflows from a probable maximum precipitation (PMP) event. The study focused on the 1.81 MAF reservoir size and the assumptions of the study included a completely full reservoir with a WSE of 520 feet at the start of the storm, a dam crest elevation of 540 feet, and a reservoir inundation area of 14,000 acres. The results of this analysis are also applicable to the 1.27 MAF reservoir, which is in the same location as the larger reservoir and has very similar drainage areas.

The PMF analysis for the 1.81 MAF reservoir determined that the PMP the watershed would experience during a three-day event was 20.63 inches. The total volume of inflow into the reservoir would be 78,422 AF with a peak inflow of 68,500 cfs during the storm. Storing the full runoff in the reservoir above the normal maximum water level would raise the WSE by approximately 5.2 feet. After the PMP event, the freeboard left in the 1.81 MAF reservoir would be approximately 14.8 feet (Sites Reservoir PMF analysis from August 2004.)

As mentioned above, the storm inflow volume for the 1.27 MAF reservoir would be approximately the same for the 1.81 MAF reservoir. The 1.27 MAF reservoir would have a maximum normal operating elevation of 480 feet (based upon the available area capacity curve for the reservoir site) and a dam crest elevation of 500 feet. Storing the full runoff in the reservoir above the normal maximum water level would raise the WSE by approximately 6.25 feet. After the PMF event, the freeboard left in the 1.27 MAF reservoir would be approximately 13.75 feet.

2.6.2 Emergency Signal Spillway Design Flood

Preliminary design of the Sites Reservoir emergency spillway was performed in accordance with the state of practice for dam appurtenant structures. The emergency signal spillway design conforms to existing Division of Safety of Dams (DSOD) criteria. The elevation, type, and capacity of the emergency spillway, are designed for a highly unusual set of circumstances.

The proposed Sites Reservoir in either the 1.81 MAF or 1.27 MAF configuration would accommodate full storage of the design flood inflow with adequate residual freeboard to the dam crest. The emergency spillway would be required primarily for the improbable case where the pumping plant would continue pumping into the reservoir despite the reservoir being at maximum pool. The emergency spillway selected for the feasibility study would consist of one 7-foot-diameter reinforced concrete pipe, which would be located at Saddle Dam 6 for both reservoir alternatives. However, the spillway configuration would be different for the two reservoirs, as discussed further in Section 3. The pipe size selection is based upon maintenance and inspection considerations.

2.7 Geology

2.7.1 General

This section summarizes the geology and geotechnical conditions of the features under consideration for the proposed NODOS Project. The information in this chapter was summarized from the *July 2003 Project Geology Report No. 94-30-02, Geologic Feasibility Report, Sites Reservoir Project, Appendix to Engineering Feasibility Report*. Project Geology Report No. 94-30-02, in turn, provided a general summary of the detailed geologic reports prepared by the DOE and the DPLA, Northern District, Geology Section (Northern District). Discussions include the preliminary geologic investigations that were conducted mostly by the Northern District for the proposed project features. The aforementioned, detailed, geologic reports are referenced at the end of this technical memorandum.

Geologic conditions at the two main dam sites (Golden Gate and Sites), the saddle dam sites, and all other project facilities provide good quality rock for their respective foundations. Three important geology-related issues associated with the feasibility study were:

- Determining that geologic foundation conditions for the proposed project facilities are adequate
- Determining seismic sources for the project and fault activity at the Golden Gate and Sites Dam sites
- Evaluating sources for sand and gravel for construction materials

The data and analyses presented in this summary were used in developing preliminary design criteria for the NODOS Project.

2.7.2 Geologic Setting

The NODOS Project would be located in the foothills of the northwestern edge of the Sacramento Valley, within the border area of the Great Valley and Coast Range geomorphic provinces (Figure 2-2). The project area is underlain by Upper Cretaceous sedimentary rocks of the Cortina and Boxer Formations and alluvial deposits of the Sacramento Valley. Surficial geologic units in the project area include Pliocene to Pleistocene age deposits of the Tehama Formation, Quaternary older alluvial terrace deposits, and Holocene (Recent) alluvium, colluvium, and landslide deposits (Figure 2-3). Structurally, the reservoir site is bounded by the Green Valley thrust and Stony Creek faults to the west, and the Corning and Willows faults to the east. Passing beneath the proposed reservoir are westerly dipping fault planes of the Funks and Bear Valley segments of the Great Valley thrust fault, while the Fruto Syncline, Sites Anticline, and Salt Lake thrust fault pass through the project site in a generally north-south trend.

The proposed Golden Gate Dam site is located in a stream-cut water gap on Funks Creek within the Venado sandstone member of the Upper Cretaceous Cortina Formation. The proposed Sites Dam site is located in a stream-cut, water gap on Stone Corral Creek, within the Boxer and Cortina Formations. At these dam sites, the Cortina and Boxer Formations are part of a series of an east-dipping, Great Valley sequence of rocks exposed in the foothills bordering the eastern Coast Ranges (Figure 2-3). Directly west of the dam sites, at the saddle dam sites and in the reservoir, these rocks are folded about the axes of the north-trending Sites anticline and Fruto syncline. East of the Golden Gate and Sites Dam sites, the rocks progressively flatten beneath the western Sacramento Valley margin. The two primary rock units in both the Cortina and Boxer Formations are sandstone and mudstone. The sandstones are commonly ridge-formers and the mudstones are generally expressed as topographic lows.

In addition to the folds, numerous faults offset and deform the bedrock strata in the study area. Two primary sets of surface faults were mapped in the vicinity of the dam sites:

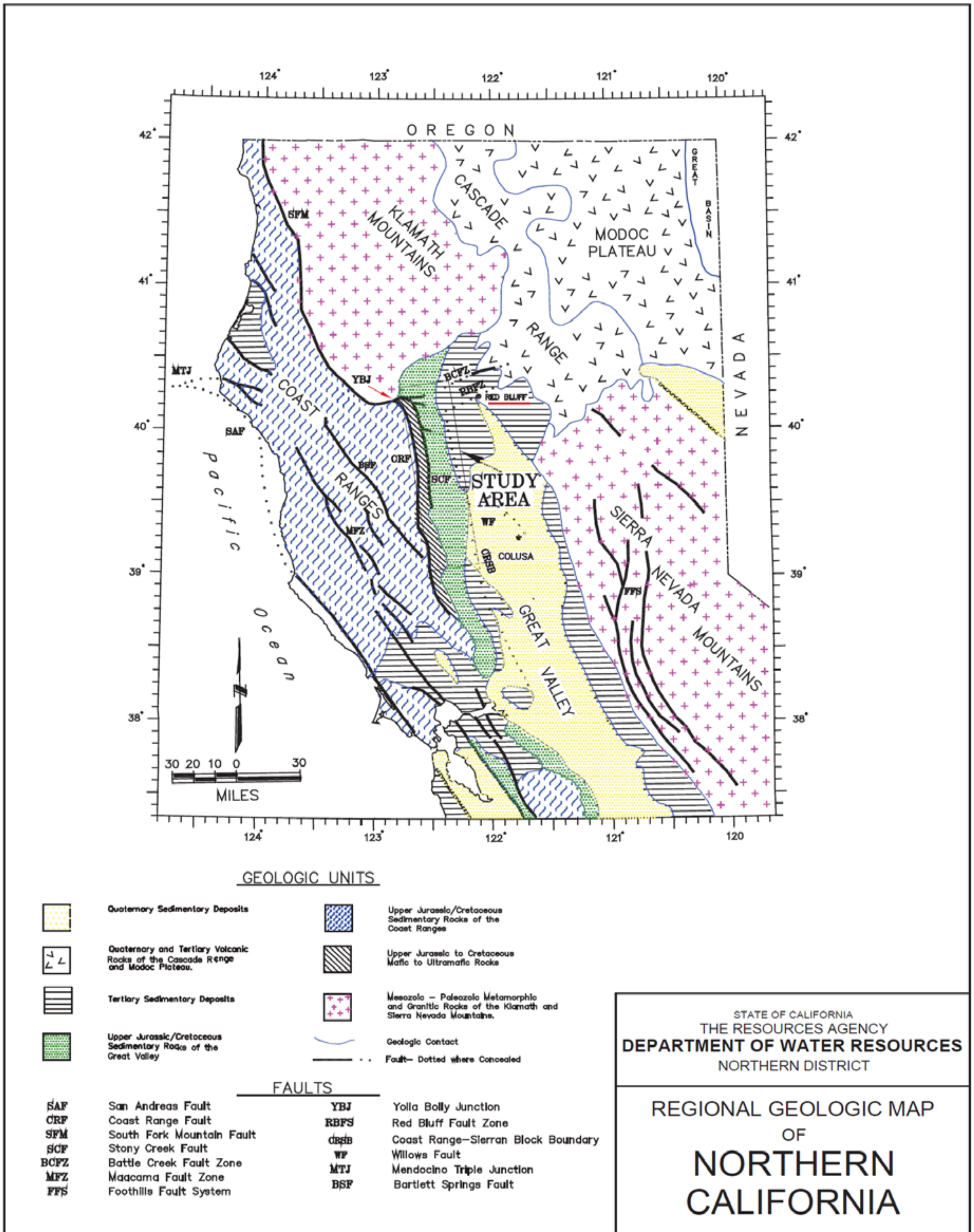
- Northeast-striking, high-angle faults that obliquely cut the north-striking bedrock units, and consistently displace stratigraphic contacts in a right-lateral strike-slip sense. Specific examples of these structures include the informally named GG-1, GG-2, GG-3, and S-2 faults, all of which pass directly through or near the proposed Golden Gate and Sites Dam (Figure 2-3).

- North-striking faults which are generally parallel to bedding. The most laterally continuous example of these structures is the steeply east-dipping Salt Lake thrust fault, which is parallel to, and directly east of, the axis of the Sites anticline in the proposed reservoir area. This fault trends through the middle of the reservoir and through the proposed Saddle Dam 2 site.

2.7.3 Geotechnical Investigations

Geologic exploration for investigation at the various NODOS Project features consisted of geologic mapping, drilling and water pressure testing, seismic refraction surveys, trenching and test pits, and laboratory testing. Individual exploration techniques are discussed below.

Figure 2-2. Regional Geologic Map of Northern California



Filename:N:\NDSharedInfo\typing\geo\Final 1999 Sites Report\Figures\original\Figure 3--Sites Regional Geology--01-19-01--JHM.dwg

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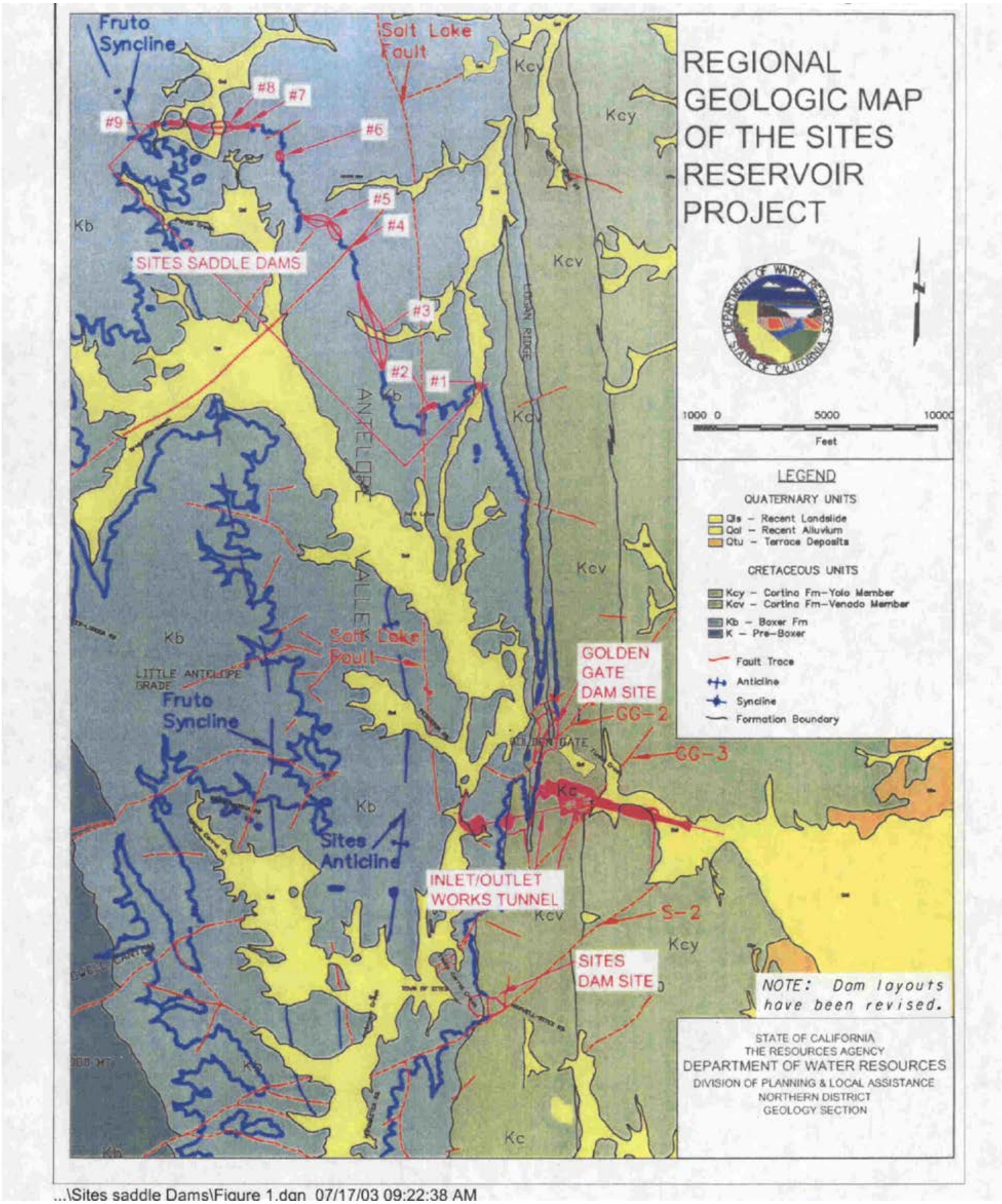
Figure 2-3. Regional Geologic Map of the Sites Reservoir Project



Note: Saddle Dam locations are for the 1.81 MAF Reservoir. Only Saddle Dams 1, 3, 5, 6, and 8 would be required for the 1.27 MAF Reservoir.

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- DWR’s Division of Land and Right-of-Way (DLRW) produced new topographic maps from a 1:7200 aerial flight in November 1998. Contours were developed at 2-foot intervals. Most of the geologic maps for the project utilized this topographic base map.

Numerous sources of previous geologic mapping were utilized in developing site maps for individual features of the NODOS Project. The first published source of geologic mapping that covers the entire project area is the USGS Oil and Gas Investigations Map OM-210, entitled *Geologic Map of the Lodoga Quadrangle, Glenn and Colusa Counties, California*. The mapping was performed by R.D. Brown and E.I. Rich in 1961 at a scale of 1:48,000. This detailed regional geologic mapping covers the entire reservoir area and was the geologic base map for all of the studies performed by Reclamation and DWR since 1963.

In 1963 and 1969, Reclamation performed feasibility level geologic mapping at a scale of 1 inch = 200 feet. In addition, in 1979 and 1980, Reclamation performed additional geologic site mapping utilizing metric scales and topography. Geologic mapping and subsurface exploration for the NODOS Project have been ongoing since 1997, by numerous DWR geologists. Geologic mapping for the reservoir site was primarily conducted by Northern District personnel between 1997 and 2001, with contributions by DOE engineering geologists.

Most of the subsurface exploration to date has been concentrated at the Sites, Golden Gate, and saddle dam sites. However, some reservoir and fault mapping, along with trenching associated with fault studies carried out by William Lettis & Associates Inc. (WLA), were conducted independent of individual dam site studies. Approximately 72 exploration borings were drilled in the project area by Reclamation and DWR, using a combination of rotary coring and hollow-stem auger methods. Standard penetration tests (SPT), water pressure/packer tests were performed in the boreholes as appropriate, and samples collected for laboratory testing. WLA excavated 31 trenches and test pits at 14 locations for their faulting and seismicity studies, while Reclamation and DWR excavated 10 test pits for construction material evaluations. Ten seismic refraction arrays were surveyed for the project, six at the Golden Gate Dam site and four for the Funks Reservoir enlargement and Delevan pipeline alignment.

Laboratory testing was performed on rock and soil samples collected from test pits, drill holes, and the nearby Sites Quarry for potential construction materials use. The testing was performed by the United States Army Corps of Engineers (USACE), Reclamation, and DWR over different periods of exploration. Testing of rock included specific gravity; absorption; compressive, shear, and tensile strengths; and Los Angeles abrasion losses. Petrographic analyses of weathered and fresh Venado sandstone were performed by the USACE in 1962 and 1972. Soil samples were tested for classification, density, permeability, and shear strength; soil samples from auger holes along the proposed conveyance alignment were also tested for resistivity, sulfates, and chlorides. Results of laboratory testing can be found in *Material Investigation, Testing, and Evaluation Program* (DWR, 2002).

2.7.4 Geologic Conditions

Sites Reservoir

The proposed Sites Reservoir would lie on alluvial and colluvial deposits and interbedded mudstone, sandstone, and conglomerate bedrock of the Cretaceous Boxer Formation (Figure 2-3). However, a comprehensive geologic study of the entire reservoir has not as yet been completed. Most of the previous exploration has focused on the Sites, Golden Gate, and to a lesser extent, the saddle dam sites. Figure 2-4 provides an explanation of symbols for individual dam site geologic maps.

Golden Gate Dam would be founded on sandstone (Kcvs) and mudstone (Kcvsm) of the Cortina Formation that generally strike north-south and dip 50º downstream to the east (Figures 2-5A, 2-5B, 2-6, and 2-7)

The sandstone is moderately to well indurated (hardened), and thin to thick bedded with mudstone interbeds up to 5 feet thick. Near the surface, the sandstone is intensely to moderately weathered, moderately hard, moderately strong, and closely to moderately fractured. At depth, the sandstone improves from slightly weathered to fresh, hard, strong, and moderately to slightly fractured. Fractures are generally associated with jointing, and are mostly healed with calcium carbonate. Overlying the bedrock, within the Funks Creek channel, is recent alluvium (Qal) consisting of silty and poorly graded sand and gravel deposits up to 17 feet thick. There are also up to 25 feet of older, sandy, and lean clay alluvial terrace (Qoal) deposits along the channel banks.

The mudstone unit at the site is moderately indurated, thinly laminated to thinly bedded with thin sandstone interbeds, and not exposed on the surface within the dam footprint. Nearby outcrops show that weathered mudstone is friable to low hardness, weak, closely fractured, brittle, and susceptible to slaking when exposed to air or moisture. At depth, fresh mudstone is moderately hard, moderately strong, and slakes only slightly after prolonged exposure to air. Bedding plane fractures predominate, while joint fractures are relatively short and discontinuous; mudstone bedding plane fractures commonly exhibit some plastic deformation in the form of slickensides or internal shearing.

Shears associated with bedding were noted in the sandstone and mudstone units, with zones up to 3.7 feet thick. The shears commonly contained up to 10 percent clay gouge with a variable percentage of calcite healing.

Two primary joint sets were identified from surface mapping at the site (Figures 2-5A and 2-5B). Set A, trending nearly normal to the ridges and bedding, has a strike ranging from N68°E to N86°E, and dips steeply from 67° north to 79° south. Set B is nearly parallel to bedding, and strikes north-south to N25°W, dipping 53° to 79° east. Analysis of the field mapping also showed a minor joint set, Set C ranging in strike from N48°-58°W and dipping 54° to 74° south.

Two near-vertical, northeast-trending faults are located at the Golden Gate Dam site, GG-1 and GG-2 (Figures 2-5A and 2-5B). Fault GG-1 is located approximately 150 to 400 feet upstream of the left abutment exhibiting right-lateral displacement of up to 250 feet. The second fault, GG-2, is located approximately 650 feet southeast (downstream) of the left abutment, passing under the downstream footprint, and traversing across the upper right abutment. GG-2 trends approximately N50°E, and displays a maximum right-lateral separation of approximately 1,300 feet.

Some colluvium, minor landslides, rockfalls, and surficial slumps are present within the footprint of the proposed dam (Figures 2-5A and 2-5B). They do not appear to pose any construction problems, or ultimate dam safety/foundation problems. Current rock falls are associated with older quarry operations. Stripping of these materials would be required to reach a suitable foundation.

Water pressure testing in exploration drill holes generally indicated that the slightly weathered and fresh foundation rock would be fairly tight, with some localized zones of potential high hydraulic conductivity near the surface. Grouting would be required.

Groundwater data was collected from monitoring wells installed during exploration drilling. Water levels in the wells ranged from elevations of 357 to 382 feet in the left abutment, 231 to 254 feet in the channel, and 392 to 437 feet in the right abutment. Based on the groundwater elevations above, dewatering would be required, as some of the dam foundation and cut-off wall excavation would be below the water table.

Figure 2-4. Explanation and Description – Symbols and Lithology

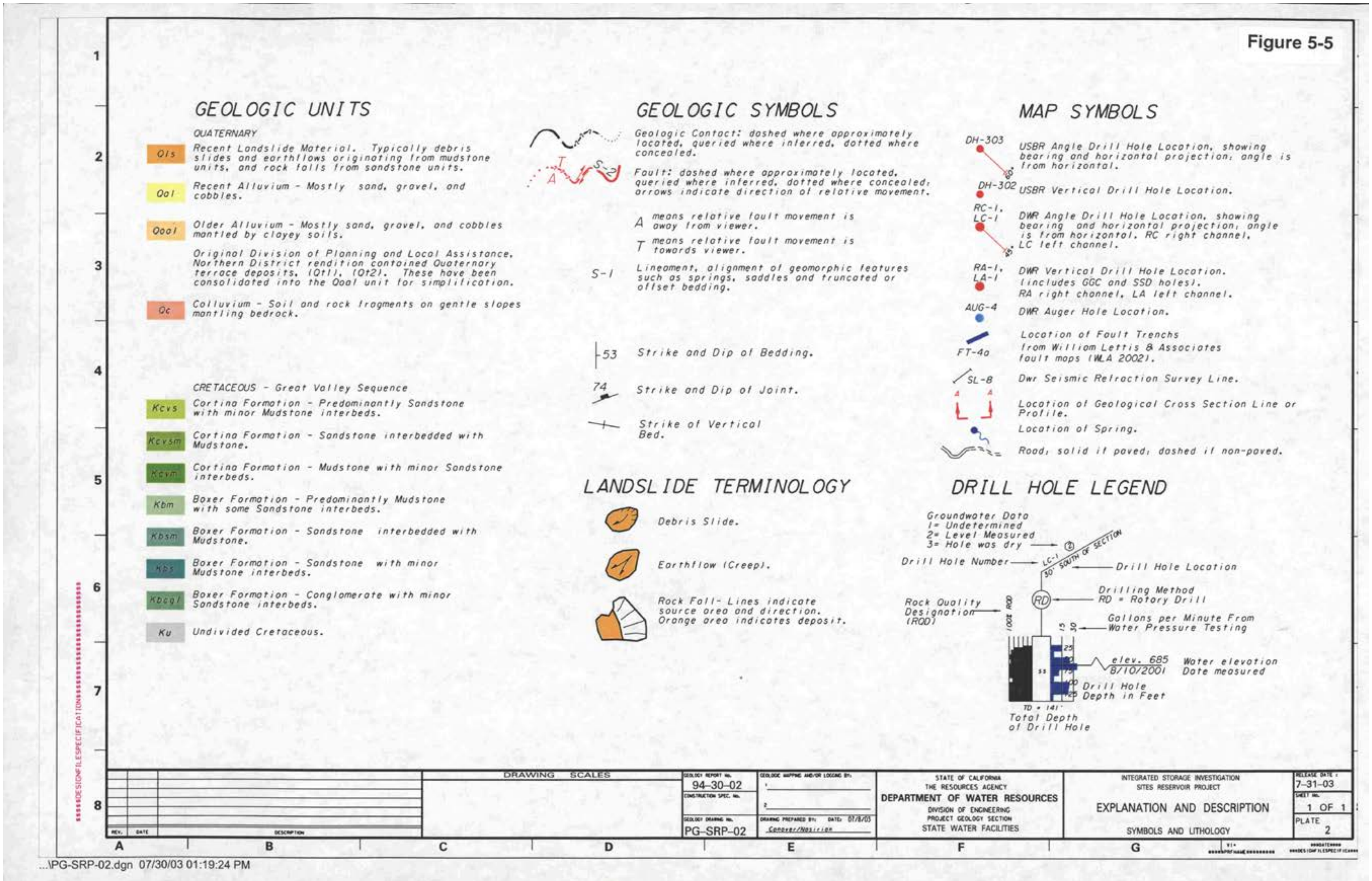

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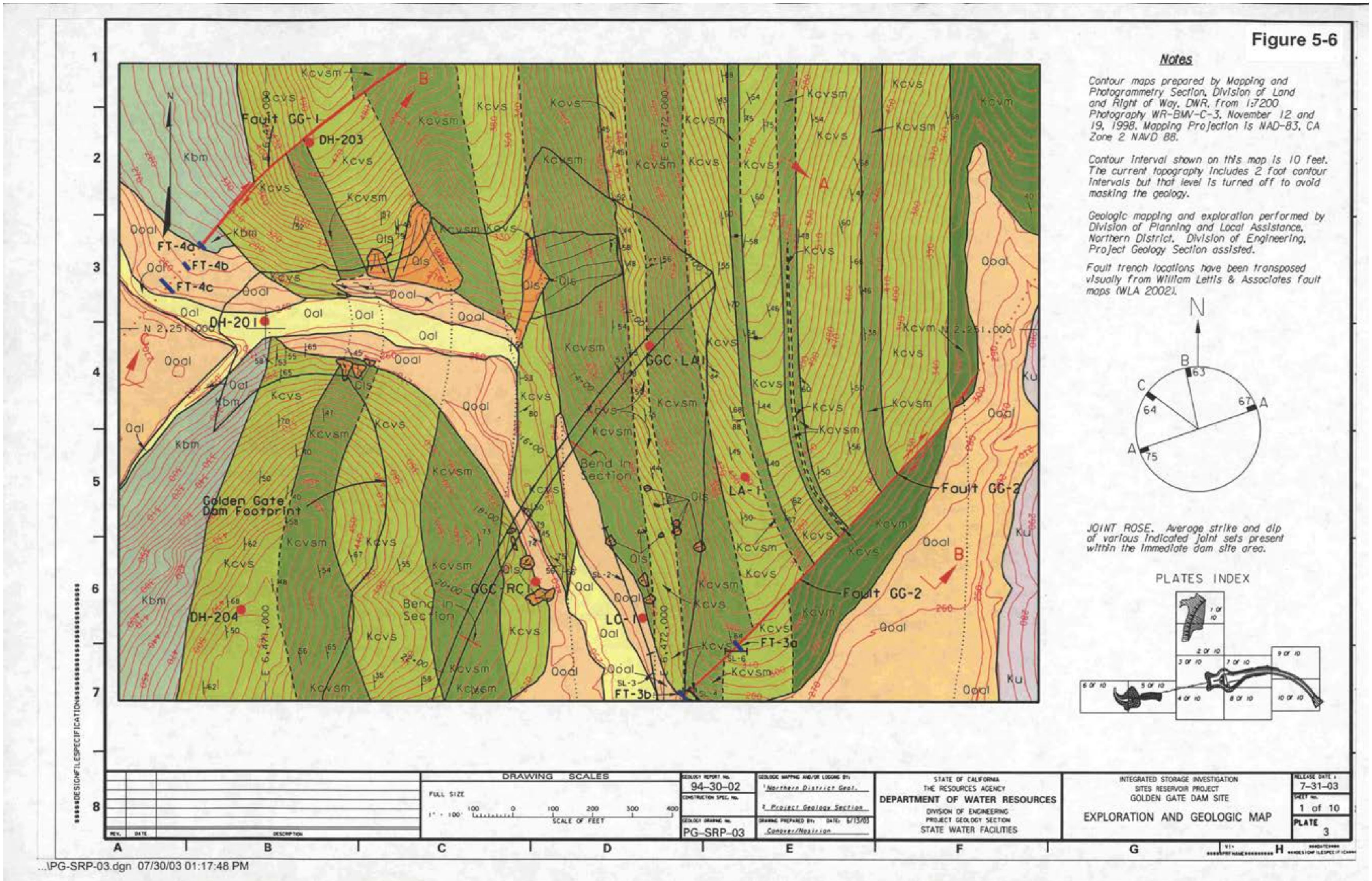
Figure 2-5A. Golden Gate Dam Site – Exploration and Geologic Map



PRELIMINARY- SUBJECT TO CHANGE

Figure 2-5B. Golden Gate Dam Site – Exploration and Geologic Map

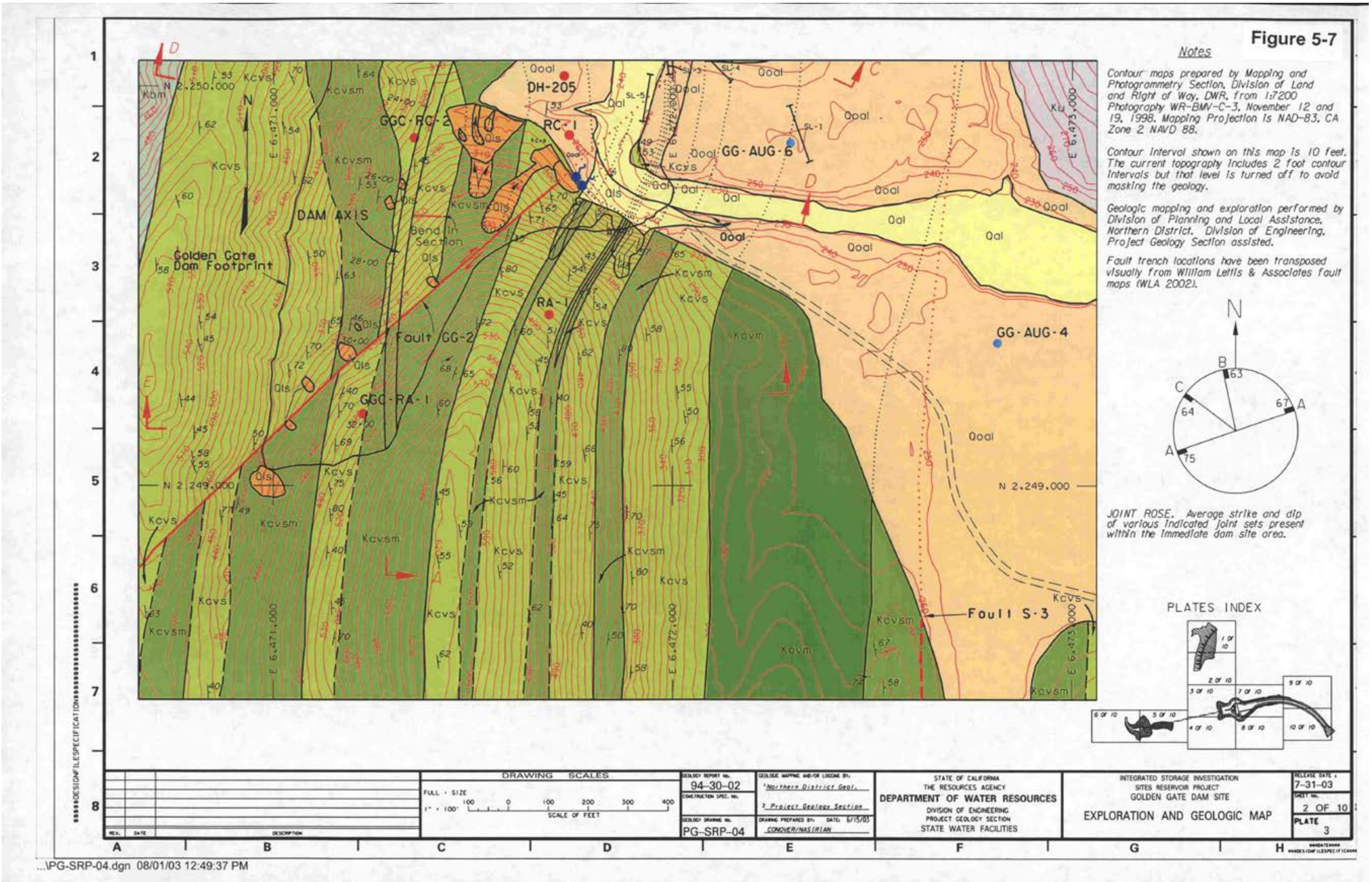


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Figure 2-6. Golden Gate Dam Site – Geologic Cross-Sections – Axial Profile A-A

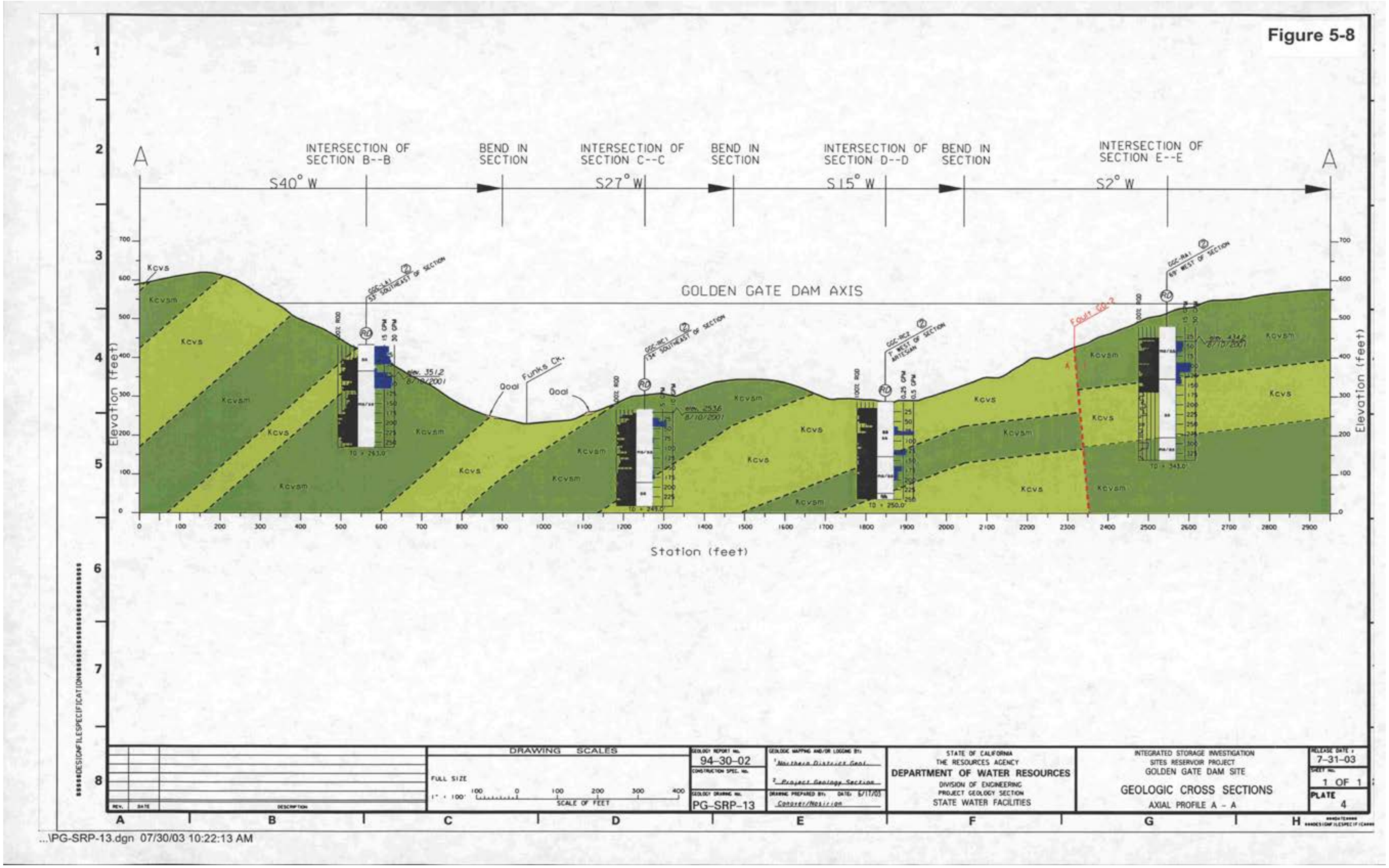

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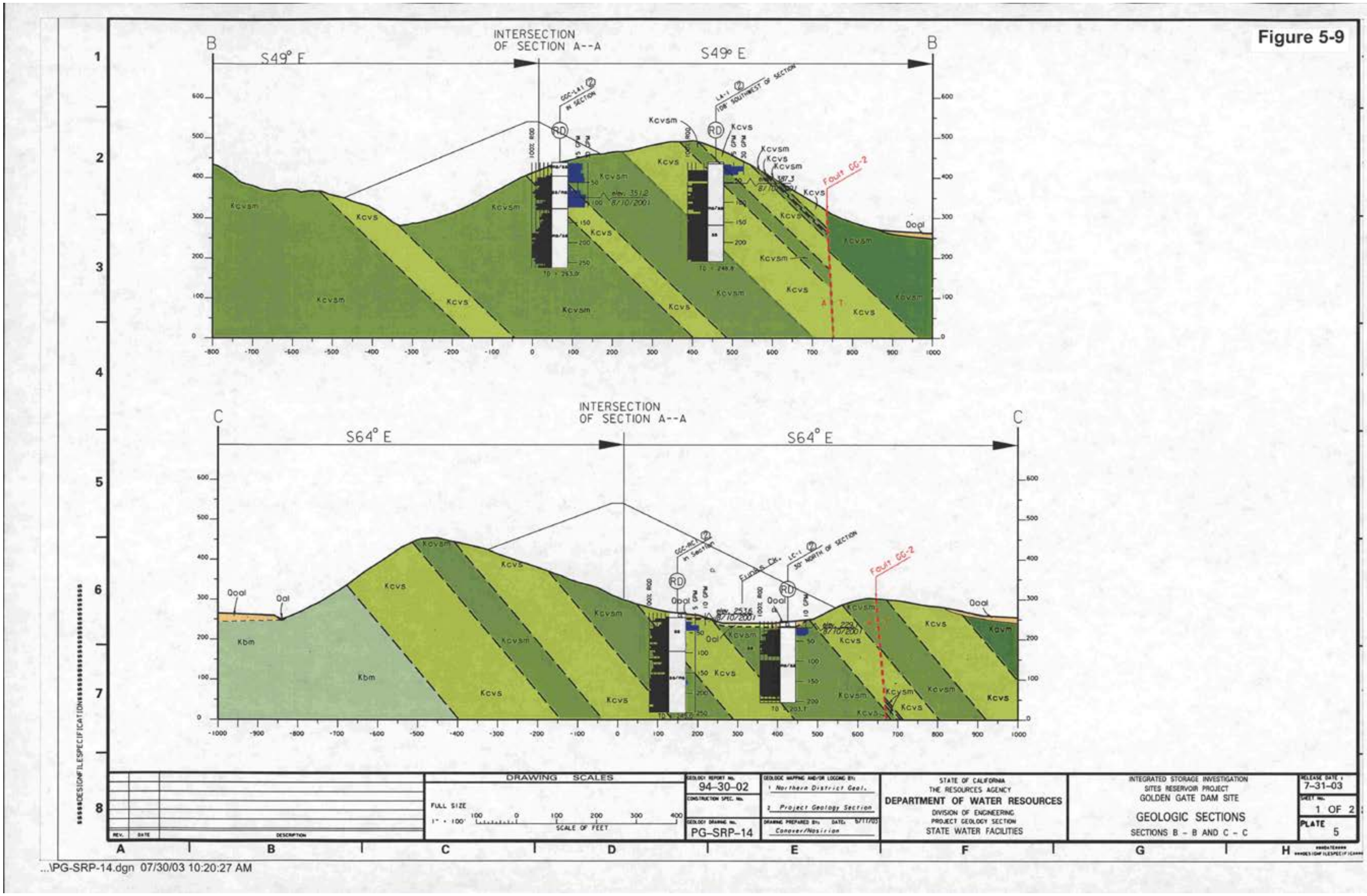
Figure 2-7. Golden Gate Dam Site – Geologic Cross-Sections – Sections B-B and C-C



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Sites Dam Site

Sites Dam would be founded on Cretaceous sedimentary rocks of the Cortina and Boxer Formations that generally trend north-south and dip 50º downstream to the east (Figures 2-8A, 2-8B, 2-9, and 2-10). The Cortina Formation consists of sandstone (Kcvs) and interbedded sandstone and mudstone (Kcvsm) of the Venado member, while mudstone (Kbm) with sandstone interbeds (Kbs) make up the Boxer Formation rocks at the site. The Stone Corral Creek channel is comprised of up to 10 feet of recent alluvium (Qal) and colluvium consisting of silty and poorly graded sands and gravels. Up to 15 feet of older alluvial (Qoal) deposits of sandy and lean clay and silt with gravel underlying silty and clayey gravels, mantle the dam abutments. In some areas, there is no soil cover and sandstone bedrock is exposed at the surface. Some landslides and surficial slumps were mapped within the footprint of the proposed dam, with the Boxer Formation more susceptible to instability than the Cortina Formation.

The Cortina Formation sandstone at the site is thin to very thick bedded with thin interbeds of mudstone ranging from laminar to 5 feet thick, and moderately to well indurated. At and near the surface the sandstone is intensely to moderately weathered, moderately hard, moderately strong, and closely to moderately fractured. At depth, the sandstone is slightly weathered to fresh, hard to very hard, strong, and closely to slightly fractured to massive. Fractures are mostly associated with jointing, and are commonly healed with calcite.

The Boxer Formation at the site is approximately 60 to 80 percent mudstone with 20 to 40 percent interbedded sandstone. The Boxer mudstone unit is low to moderately hard, weak to moderately strong, closely to moderately fractured, and very thin to thinly bedded. Fractures in the mudstone are mostly associated with bedding, and commonly exhibit some plastic deformation in the form of slickensides or internal shearing. The mudstone is susceptible to slaking when exposed to air and/or water.

Geologic mapping at the site identified two primary joint sets (Figures 2-8A and 2-8B). Set A trends nearly normal to the topographic ridges and bedding, striking between N57°E to N80°E and dipping 69° to 80° north. Joint Set B ranges in strike from N72°W to N86°W, and dips steeply from 78° north to 83° south. A minor joint set, Set C, was also identified striking approximately N74°E and dipping approximately 45° north.

Fault S-2 is a 2.5-mile-long, northeast-trending, tear fault. It is located approximately 900 feet downstream of the left abutment of the proposed Sites Dam, 700 feet downstream of the axis, and approximately 100 feet downstream of the toe on the right abutment (Figures 2-8A and 2-8B). The trend of Fault S-2 changes from approximately N60°E at the right abutment toe, to N70°E midway up the right abutment. In their fault trench studies, WLA determined that Fault S-2 is a narrow, sub-vertical bedrock shear zone that has a maximum right-lateral separation of approximately 550 feet.

Figure 2-8A. Sites Dam Site – Exploration and Geologic Map

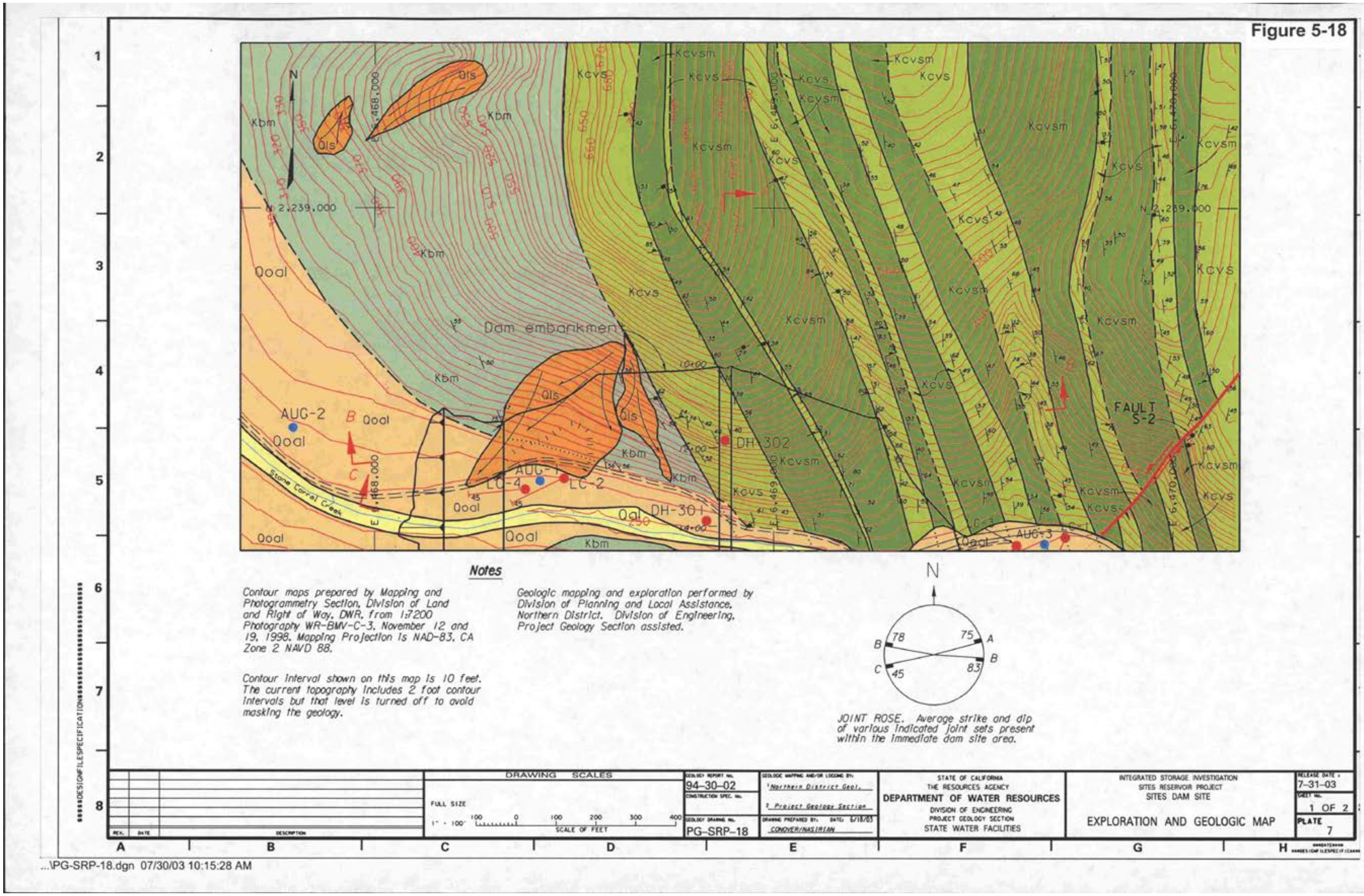

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Figure 2-8B. Sites Dam Site – Exploration and Geologic Map

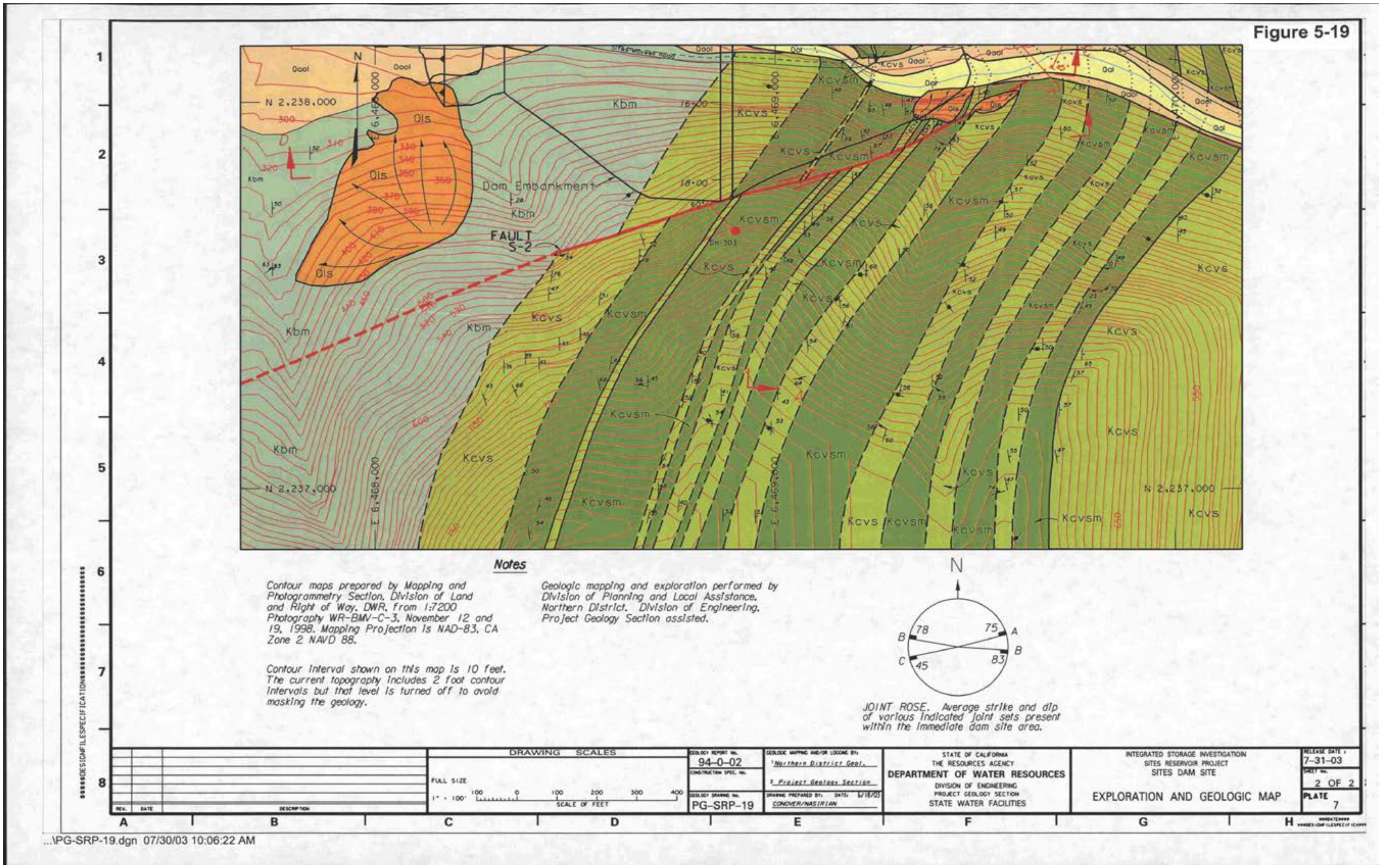

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Figure 2-9. Sites Dam Site – Geologic Sections – Sections A-A and B-B

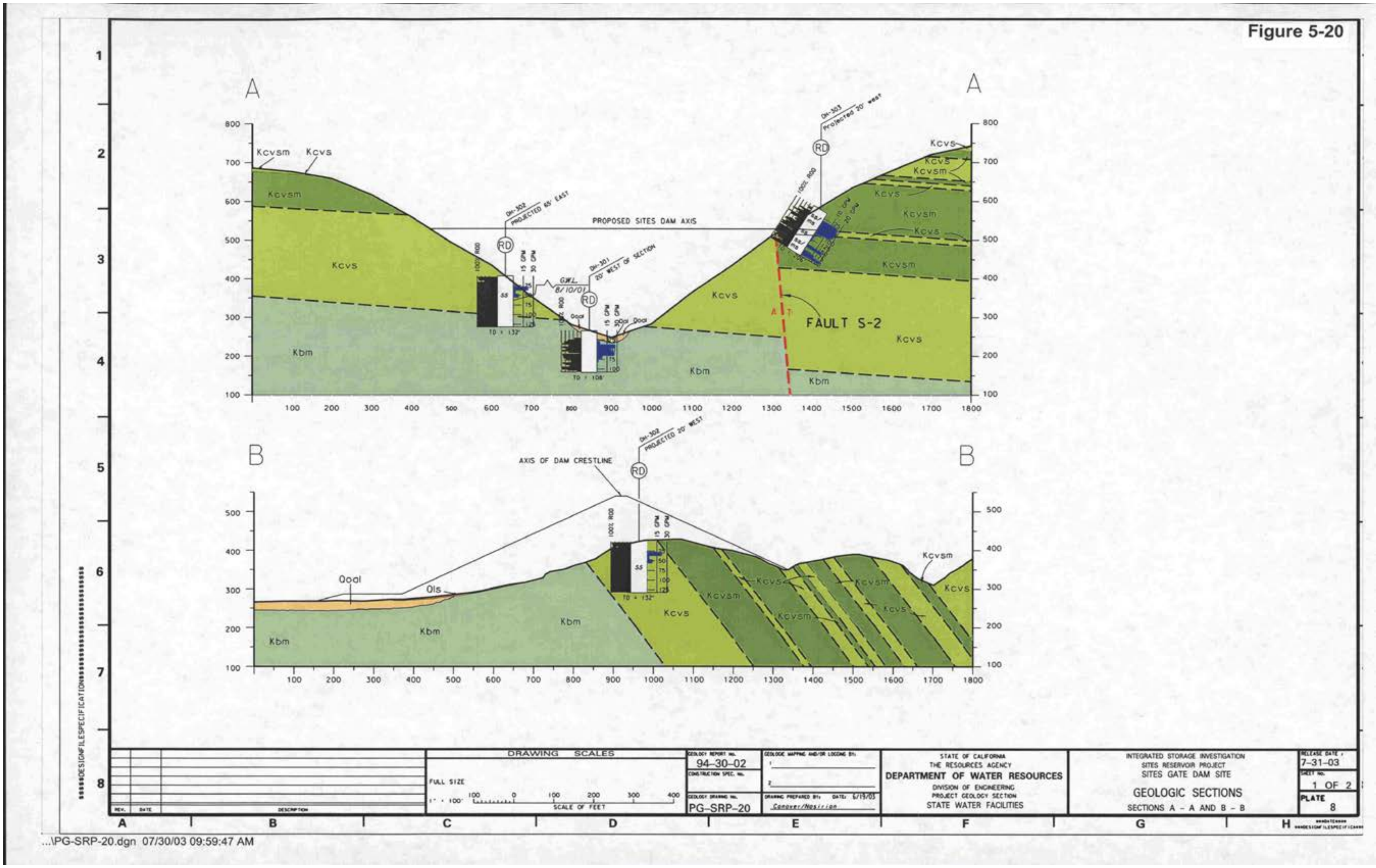

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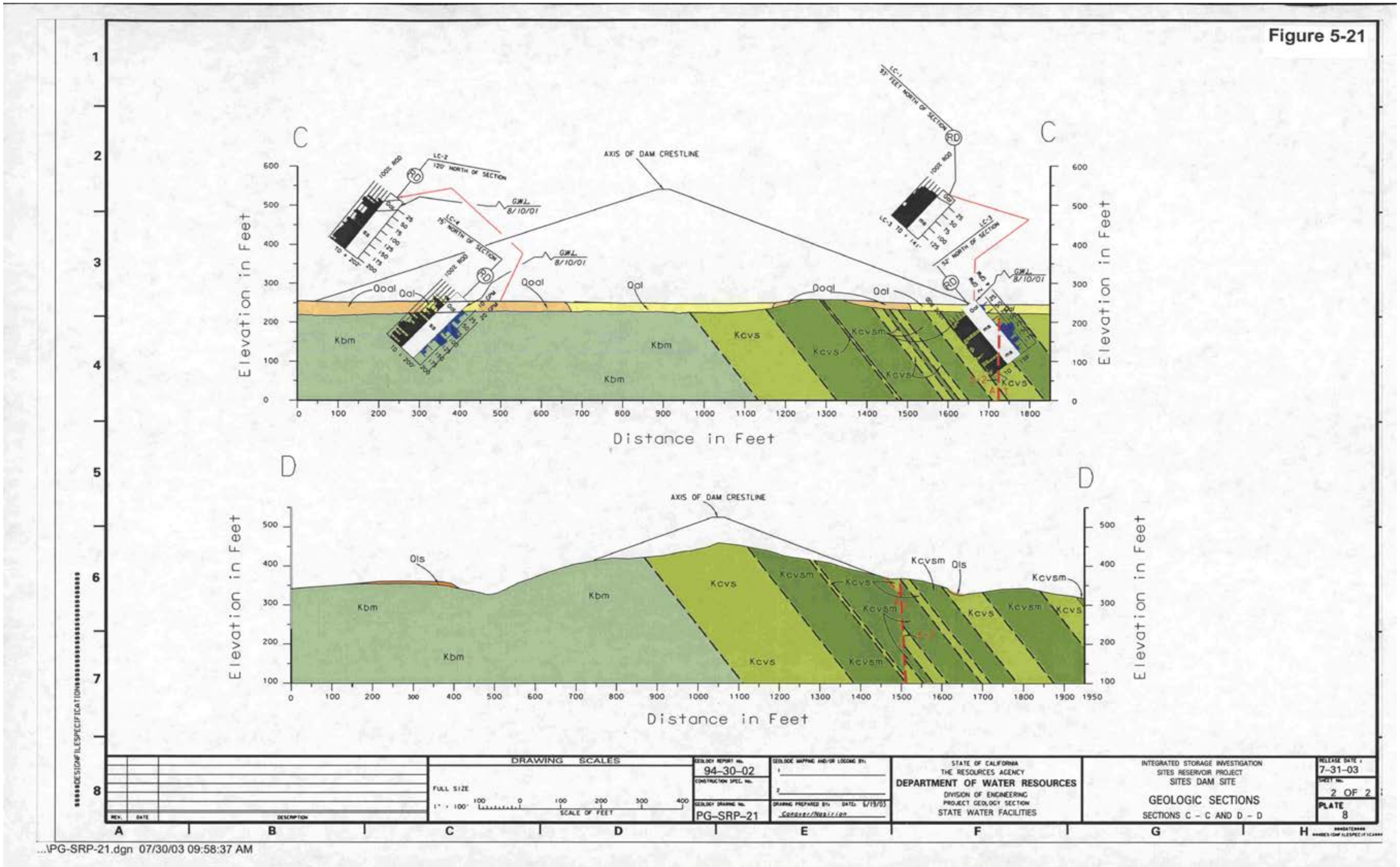
Figure 2-10. Sites Dam Site – Geologic Sections – Sections C-C and D-D



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Several landslides and slumps were identified in both the right and left abutments (Figures 2-8A and 2-8B). Two landslides were mapped on the left abutment, in Boxer Formation mudstones, within the footprint of the dam, upstream of the axis. Both are considered small, do not exceed a depth of 30 feet, and would be removed during excavation of the abutment. A larger slide of just under 6 acres was mapped on the right abutment, approximately 600 feet upstream of the axis, within the upstream portion of the dam footprint (Figures 2-8A and 2-8B). A toe bulge of up to 3 feet was observed in the western edge of the slide, but no bulge was detected to the east (inside the footprint). The depth of this slide does not appear to exceed 35 feet. Two additional minor landslides were mapped at the downstream toe of the right abutment, within the Cortina Formation.

Water pressure testing in exploration drill holes at the Sites Dam generally indicated that the slightly weathered and fresh foundation bedrock is fairly impermeable, with some localized zones of potentially high hydraulic conductivity closer to the surface. High water takes (more permeable zones) generally occurred to depths of 40 to 60 feet below the proposed excavation surface, with the rock mostly tight below 60 feet.

Groundwater ranged from elevations of 343 feet in the left abutment, to approximately 260 feet in the channel (representative of surface water elevations in Stone Corral Creek), and to approximately 450 feet in the right abutment.

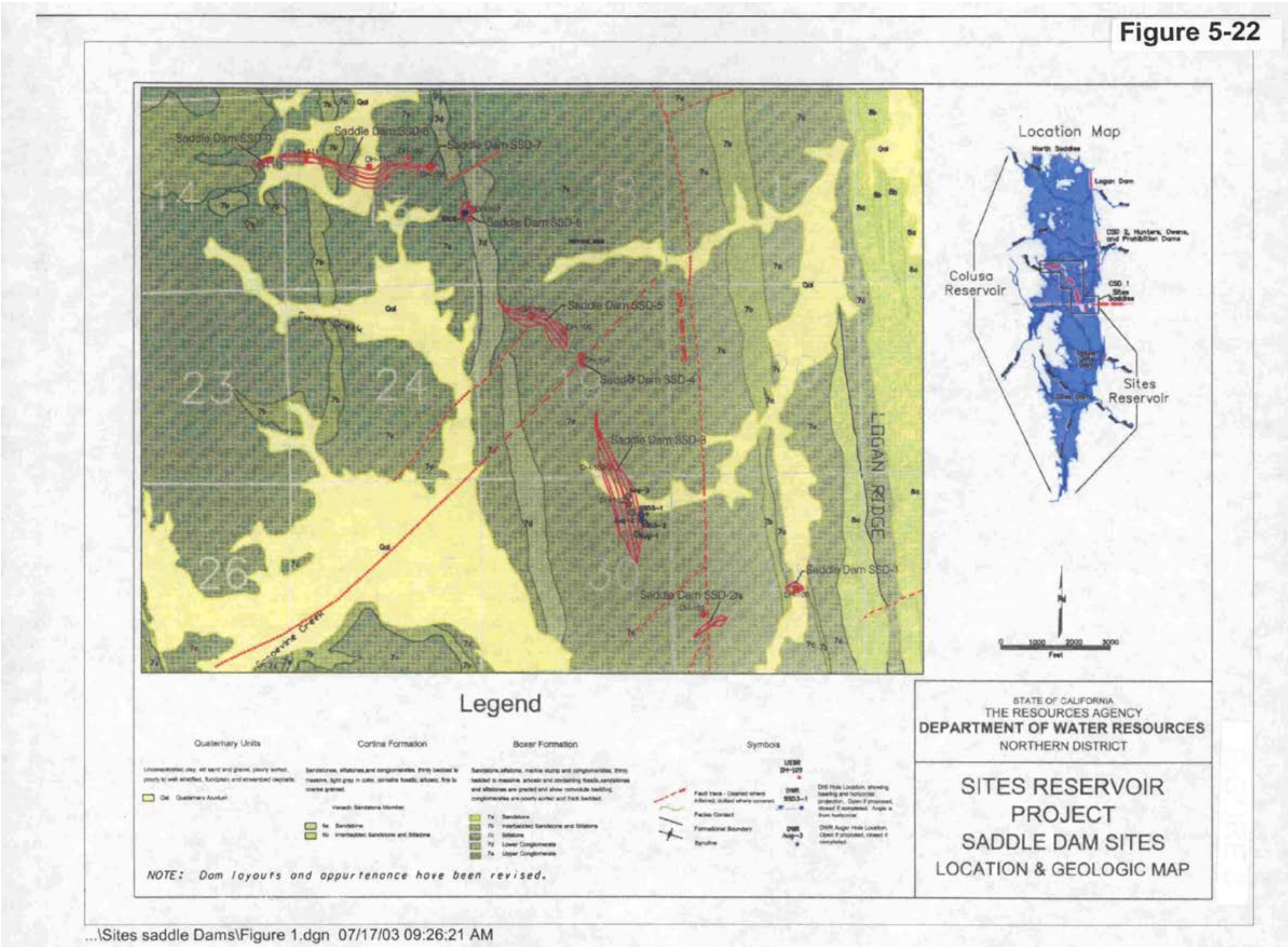
Sites Reservoir Saddle Dam Sites and Emergency Signal Spillway

The nine saddle dams and emergency spillway proposed for the 1.81 MAF Sites Reservoir are located in the northern part of the reservoir, as shown on Figure 2-11. The 1.27 MAF reservoir would have fewer saddle dams because the maximum WSE is 40 feet lower. Saddle dams would be constructed on interbedded mudstone, sandstone, and conglomerate sedimentary rocks of the Boxer Formation (Figure 2-11). Overlying the bedrock is a lean to fat clay with a sand, colluvial cover (Qc) typically ranging from 5 to 25 feet in depth. The geologic rock units strike roughly north-south with a dip that ranges from west to east depending on the location of the saddle dam with respect to the Fruto syncline, which trends just west of Saddle Dam 9. Bedding associated with the eastern limb of the syncline dips at approximately 20° west at Saddle Dam 8, and flattens to 5° west at Saddle Dam 9. Bedding dip direction gradually changes from west to east, near the intersection of the Salt Lake fault, and possibly the northern extension of the Sites anticline in the vicinity of Saddle Dam 1 and Saddle Dam 2.

Bedrock at the saddle dam sites is generally approximately 70 percent mudstone (Kbm), 25 percent sandstone (Kbs), and 5 percent massive conglomerate (Kbcgl). The mudstone ranges from decomposed to fresh, intensely to slightly fractured, friable to moderately hard, weak to moderately strong, and laminar to thinly bedded. The sandstone is thin to very thick bedded, decomposed to fresh, intensely to moderately fractured, low hardness to hard, and weak to very strong. Bedding trends between N30°W and N20°E, dipping approximately 65° to 70° east to 20° to 40° west.

The conglomerate exposed on the left abutment of Saddle Dam 5 is mostly low hardness to hard, weak to strong, intensely to closely fractured, very thick-bedded and contains 45 percent sandstone and 5 percent mudstone interbeds.

Figure 2-11. Sites Reservoir Project – Saddle Dam Sites – Location and Geologic Map



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The Salt Lake fault, judged capable of generating up to 16 inches of reverse displacement in a single event (WLA, 2002), has been projected through the left abutment of Saddle Dam 2 (Figure 2-11). A northeast trending tear fault is projected through the center of Saddle Dam 4 (Figure 2-11), but has not been verified. At least two northeast-trending shear zones, referred to as lineaments LSSD5-4 and LSSD5-3, are projected through Saddle Dam 5. Lineament LSSD5-4 is projected through the middle of the dam axis, while lineament LSSD5-3 trends through a proposed slurry wall (Figure 2-11).

Minor surficial landslides and slumps were mapped on the right abutment and upstream of the left abutment of Saddle Dam 1, but are not considered to be a problem.

Section 3.3.7 provides siting information and proposed details for the emergency signal spillway for the 1.81 MAF and 1.27 MAF reservoirs.

Sites Reservoir Inlet/Outlet Works

Two alignments were considered for the inlet/outlet tunnel from the SPGP location. The two alignments are referred to as the Long Tunnel (approximately 4,000 feet) and the Short Tunnel (approximately 2,500 feet), both with a gate shaft option or multi-level outlet works option. Both the Long and Short Tunnels are designed to be 30 feet in diameter. Initially, the Long Tunnel alignment along with the gate shaft option was investigated because it avoided the intersection of Fault GG-2 in the tunnel and only encountered the fault in the intake channel in the reservoir (Figures 2-12A through 2-12H). The geologic profile along this alignment is illustrated in Figures 2-13A and 2-13B. The Short Tunnel alignment alternative would encounter Fault GG-2 approximately 600 feet downstream of the proposed intake tower.

The proposed 30-foot-diameter concrete-lined tunnel for both the Long and Short Tunnel alignments would be through the Cortina and Boxer Formations characterized by interbedded sandstones (Kcvsm) and mudstones (Kbm). Maximum cover for the Long and Short Tunnel alignments would be approximately 550 and 400 feet,

Figure 2-12A. Golden Gate Dam Site – Exploration and Geologic Map

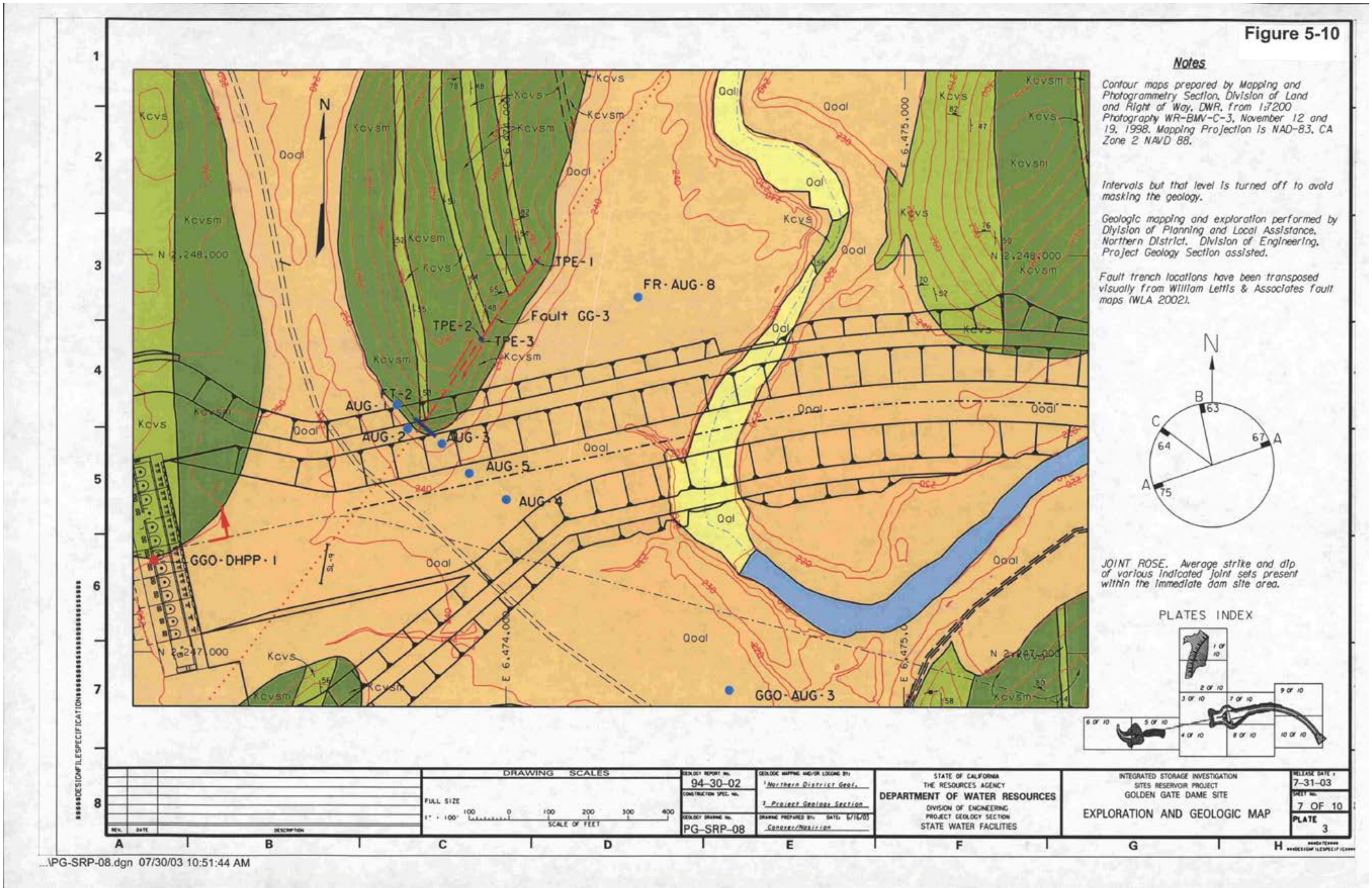

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Figure 2-12B. Golden Gate Dam Site – Exploration and Geologic Map

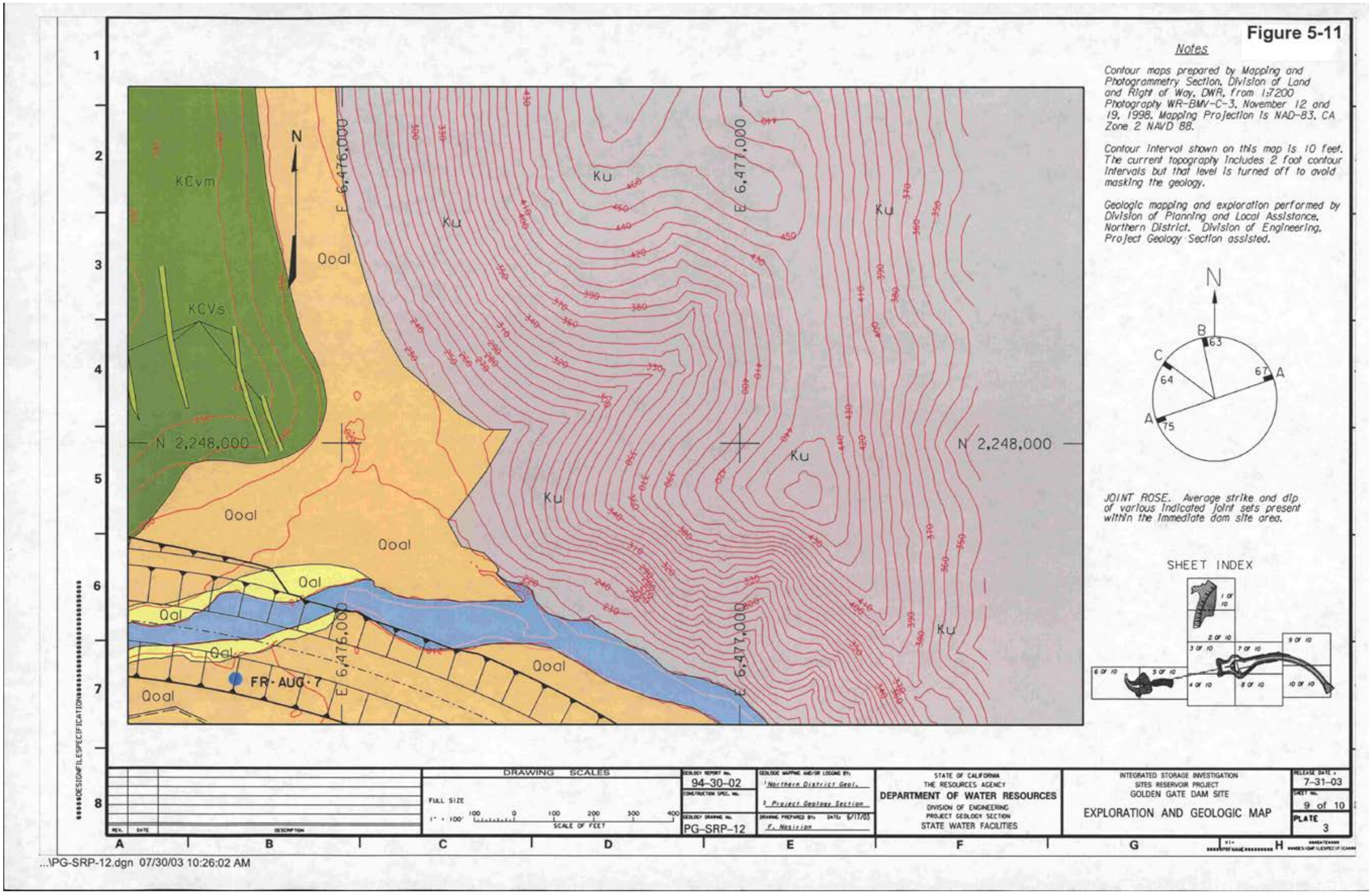

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Figure 2-12C. Golden Gate Dam Site – Exploration and Geologic Map

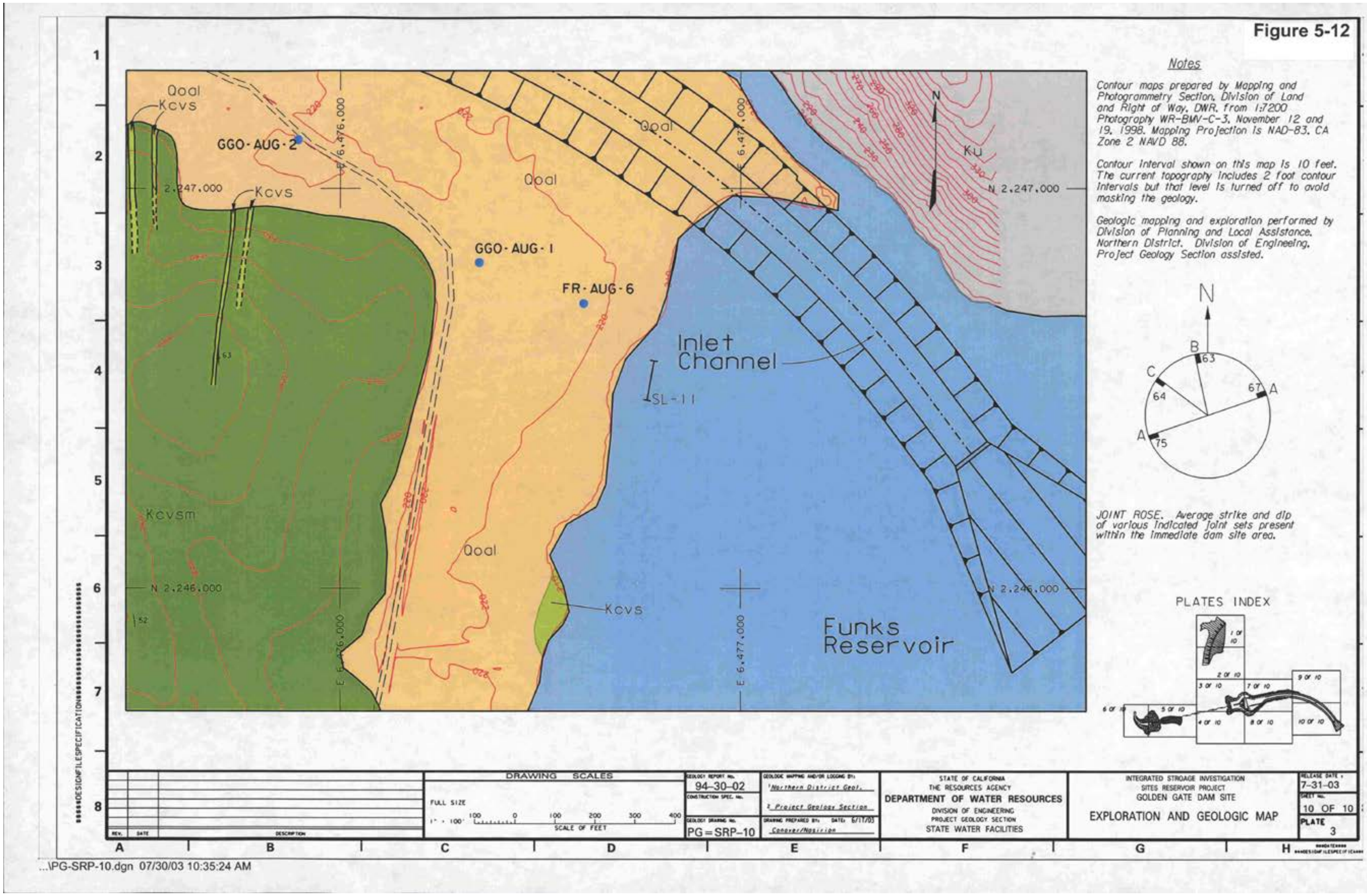

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Figure 2-12D. Golden Gate Dam Site – Exploration and Geologic Map

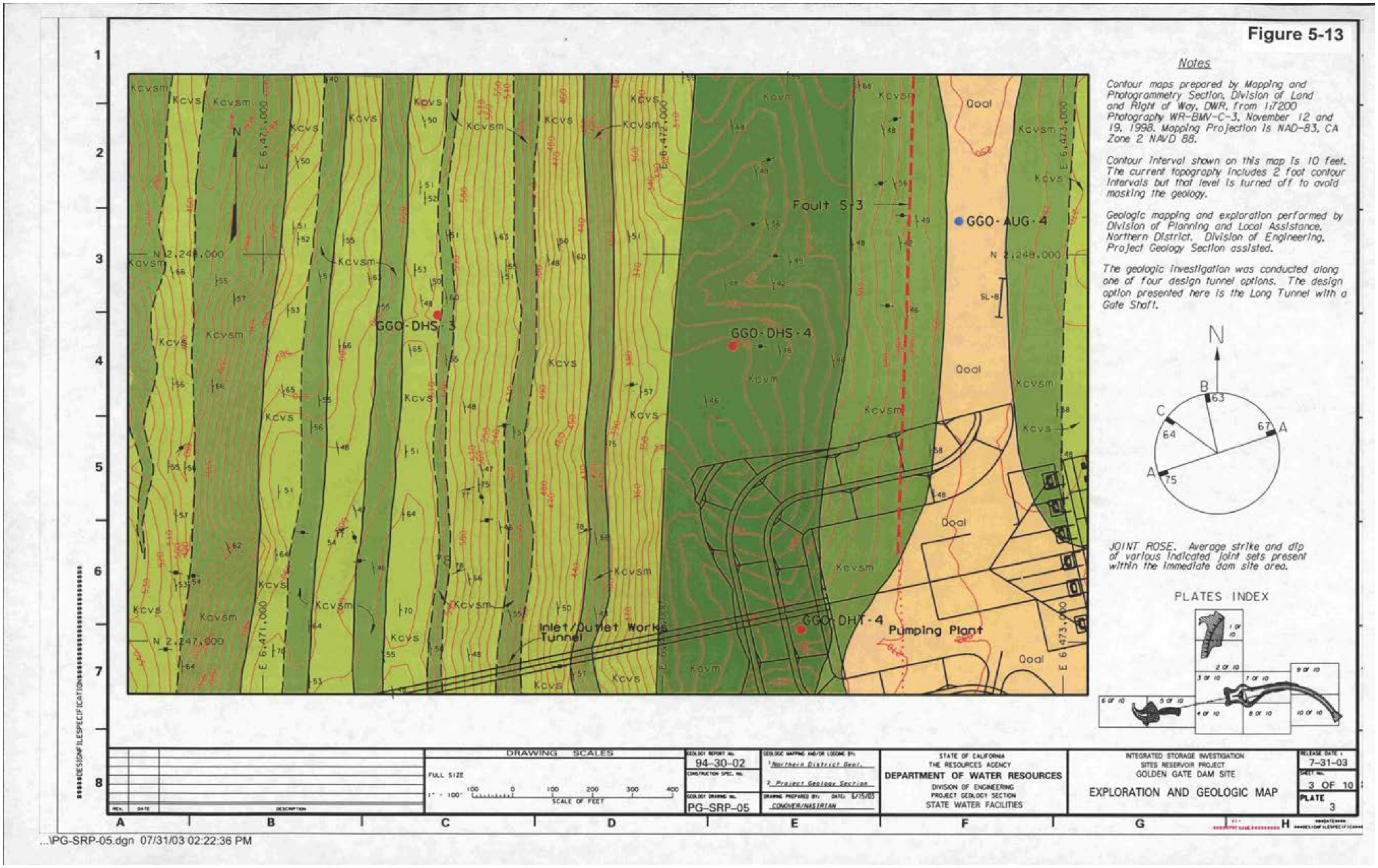

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Figure 2-12E. Golden Gate Dam Site – Exploration and Geologic Map

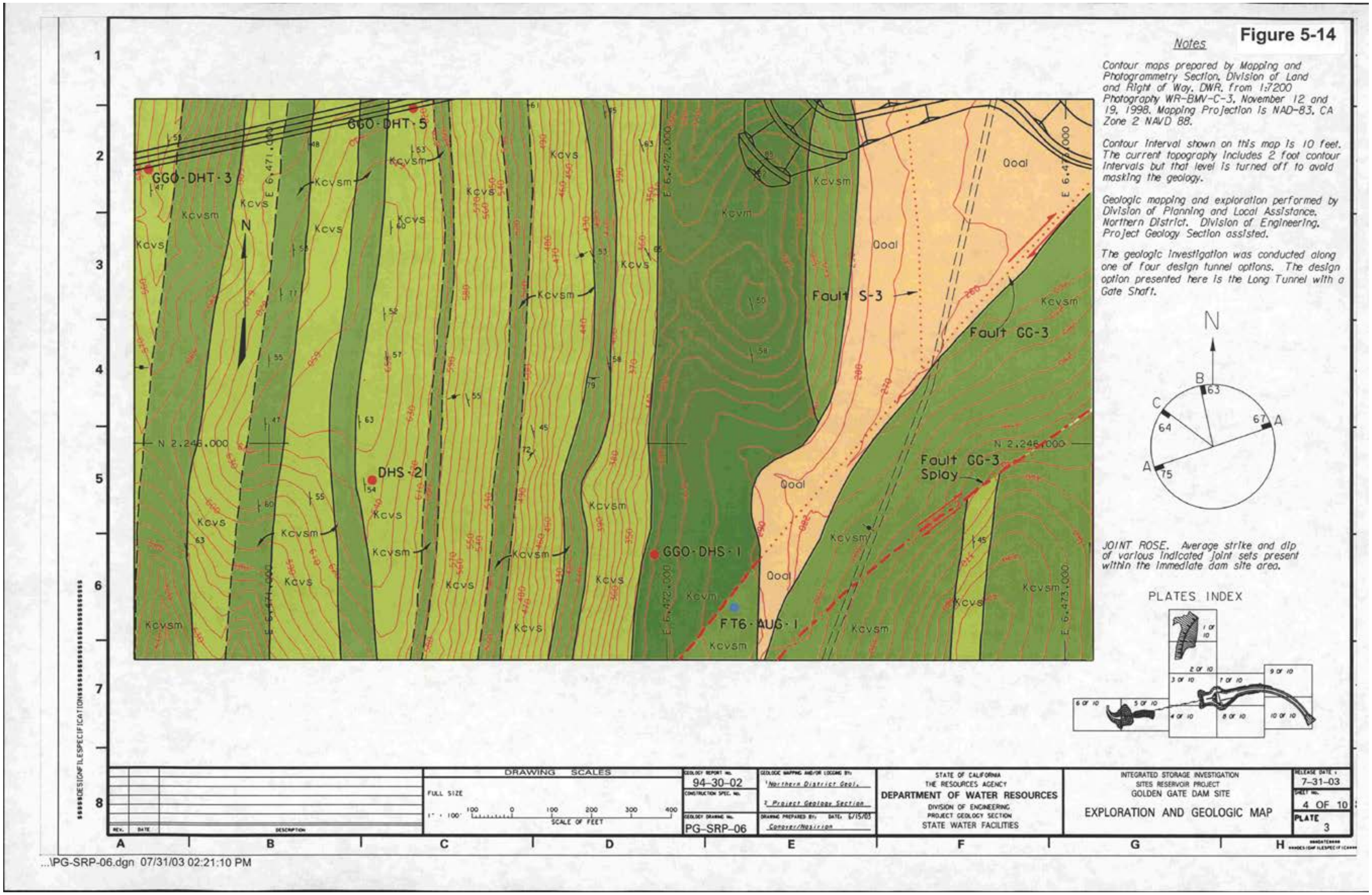

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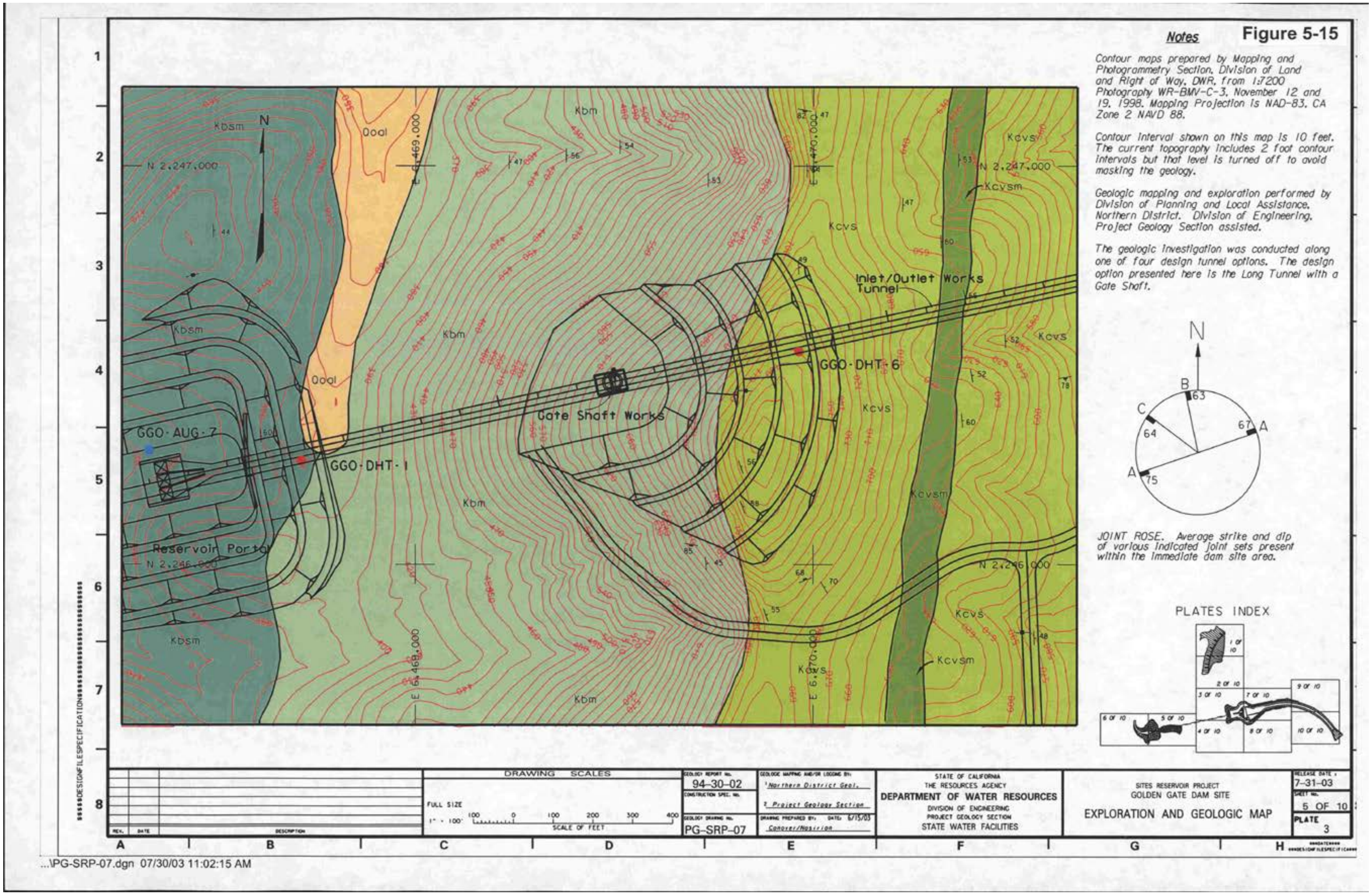
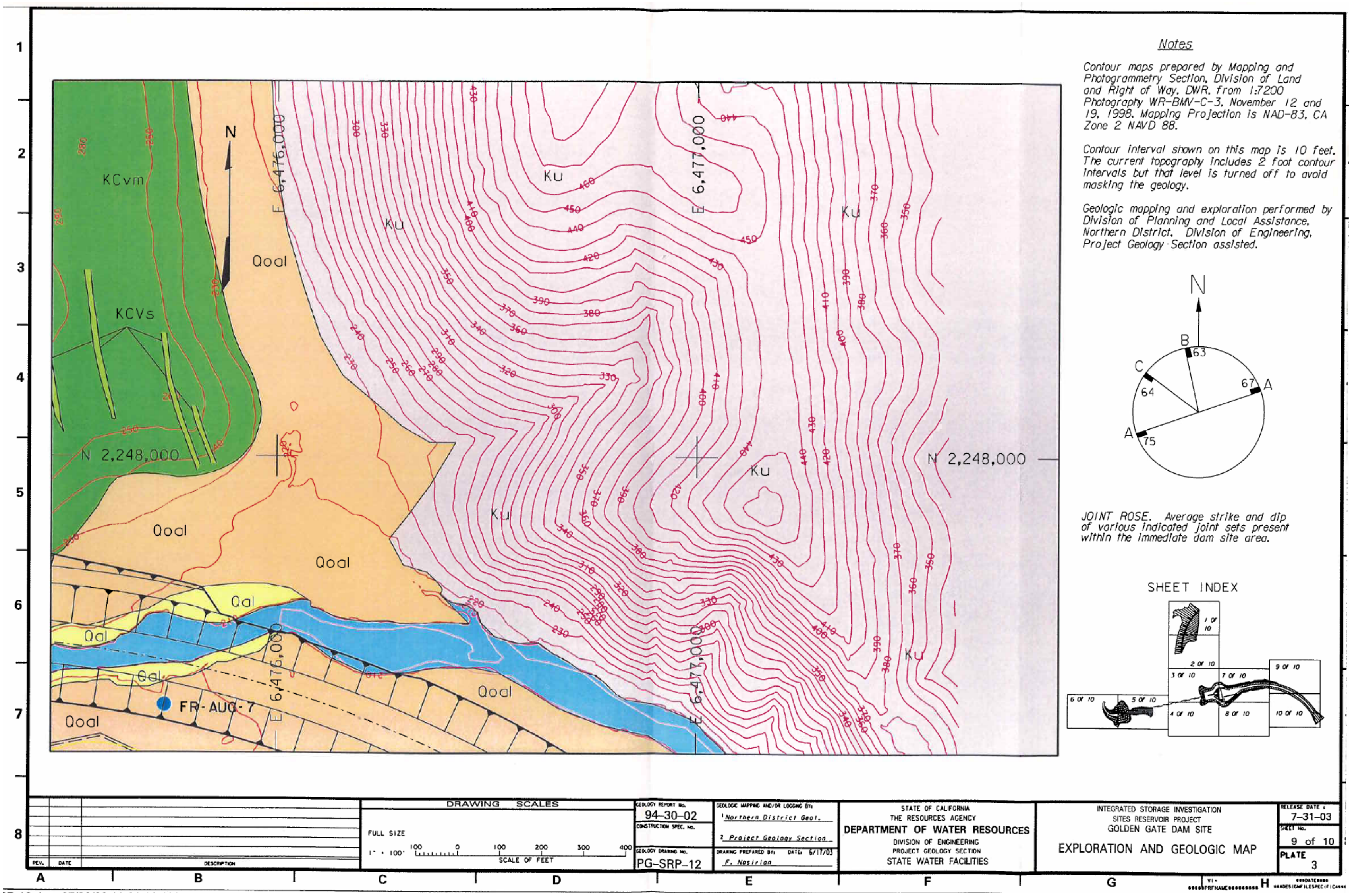
Figure 2-12F. Golden Gate Dam Site – Exploration and Geologic Map



PRELIMINARY- SUBJECT TO CHANGE

Figure 2-12G. Golden Gate Dam Site – Exploration and Geologic Map



PRELIMINARY- SUBJECT TO CHANGE

Figure 2-12H. Golden Gate Dam Site – Exploration and Geologic Map

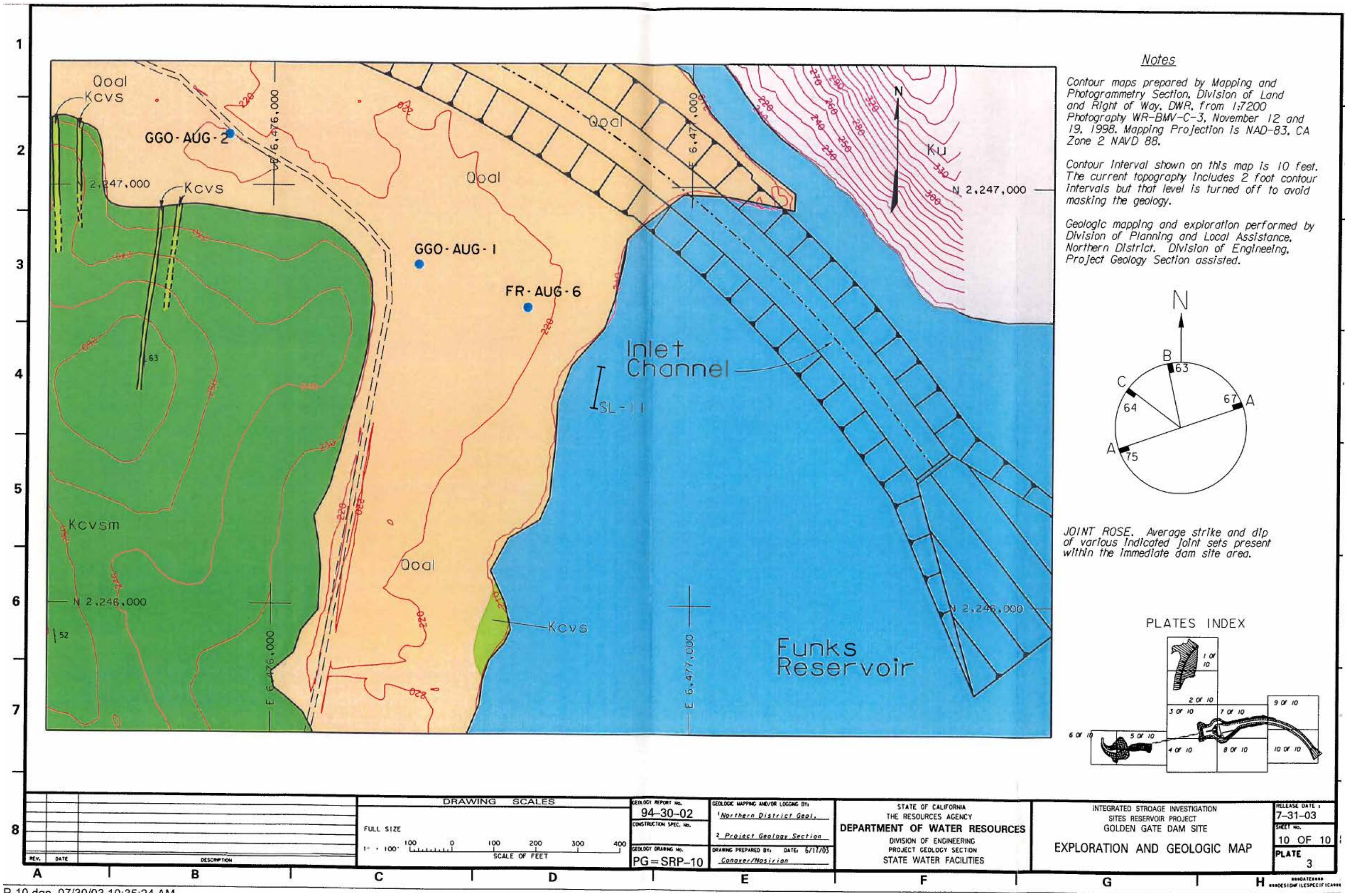


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Figure 2-13A. Golden Gate Dam Site – Geologic Sections – Outlet Tunnel Section F- F

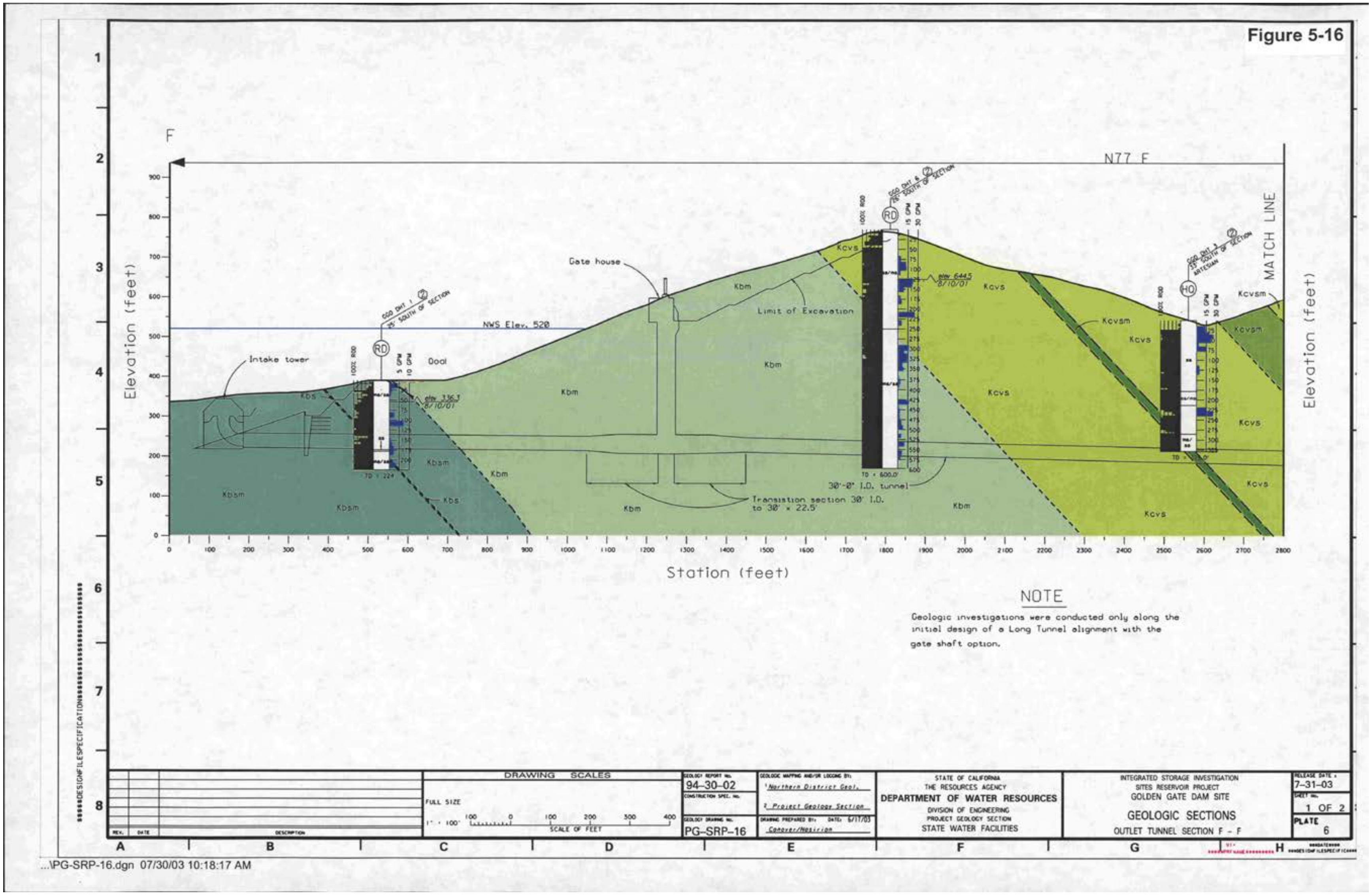

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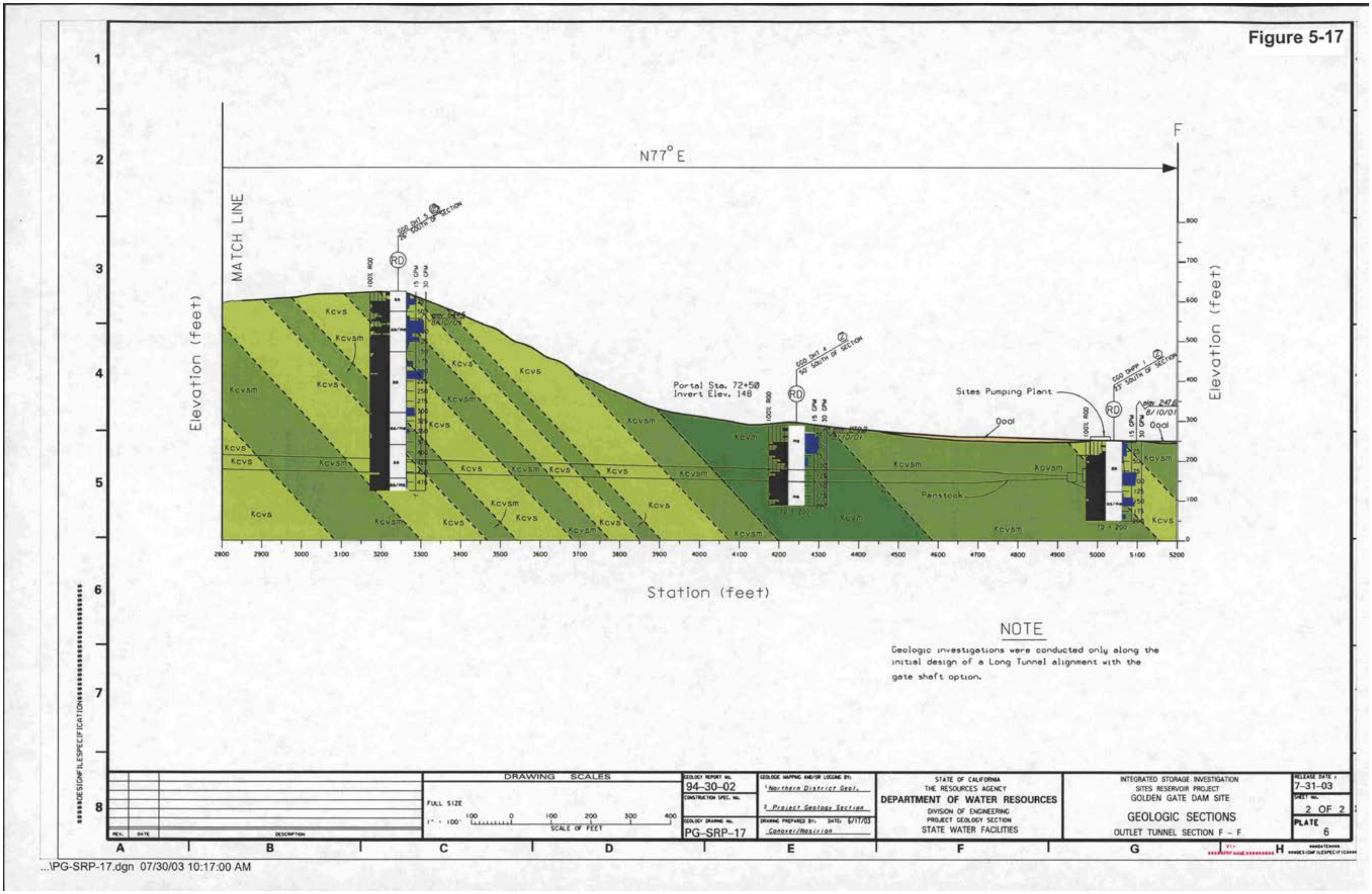
Figure 2-13B. Golden Gate Dam Site – Geologic Sections - Outlet Tunnel Section F-F



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respectively. Geologic mapping indicates that approximately 500 feet, or 20 percent, of the Short Tunnel alignment would be in the Boxer Formation, which consists of approximately 70 percent mudstone. The remaining 2,000 feet, or 80 percent, of the alignment would encounter the Cortina Formation, which is approximately 70 percent laminated to thinly-bedded mudstone with very-thinly- to thickly-bedded sandstone interbeds. The Cortina Formation consists of very thinly- to very thick-bedded sandstone with laminated to thinly-bedded mudstone.

Fresh sandstone is generally hard and strong, and fresh mudstone is moderately hard and moderately strong. Sandstone and mudstone core samples from exploration tunnel drill holes were submitted for testing. Table 8 of the Project Geology Report 94-30-02 lists the test results. Based on preliminary drill hole information, tunneling conditions through these sedimentary rocks would be good. Strike of the bedding is roughly north-south, nearly normal to the tunnel alignment, with an average dip of approximately 50º east. Drill hole logs indicate that some steeply-dipping (70^{o}) shears may be present at tunnel grade.

Some instability or minor overbreak may occur in the crown associated with laminated bedding of the mudstone. Moderate overbreak may occur along the tunnel walls where shears and associated fractured rock are present. Rock quality designation (RQD) values indicate that tunnel support requirements would utilize light to moderate weight steel sets on approximately 4-foot centers. Local areas of fractured rock associated with shearing may require heavier steel sets and/or closer spacing.

All five of the tunnel exploration drill holes showed groundwater levels well above tunnel grade, indicating that groundwater will be encountered during tunnel excavation. Figures 2-13A and 2-13B illustrate drill hole groundwater levels. One drill hole encountered artesian flows estimated to be approximately 10 gallons per minute (gpm), indicating that some isolated, confined, high groundwater flows would be encountered during the tunnel excavation. In addition, water pressure testing was performed in the tunnel drill holes to estimate permeabilities for the tilted strata, especially where they intersect the tunnel alignment. Water pressure tests at tunnel grade in the five exploration holes showed no water losses, indicating that the rock in the tunnel at these locations is fairly impermeable. Subsequent references to Funks Reservoir refer to the existing reservoir.

SPGP, Approach Channel, and Funks Reservoir

The evaluation described below was prepared at a time when the existing Funks Reservoir was to be incorporated into the NODOS Project within its existing limits. However, to enhance power generation opportunities, the Holthouse Reservoir facility (an expansion of the existing Funks Reservoir) has since been developed. Holthouse Reservoir would involve constructing a new dam east of the existing Funks Dam and breaching the existing dam to form a larger reservoir with an active storage of approximately 6,500 AF. The Sites Pumping/Generating Plant (SPGP) channel would be deepened and extended eastward beyond the limits shown on the figures referenced below to connect into the expanded reservoir. Additional geotechnical investigation would be required as part of future development work for the new dam and along the extended channel alignment.

The proposed SPGP, the associated approach channel from Funks Reservoir, and Funks Reservoir itself, are located on the eastern side of the primary ridge at the right abutment of the Golden Gate Dam. The curved approach channel would extend approximately 5,000 feet from Funks Reservoir (Figures 2-12E through 2-12H).

Sandstone with interbedded mudstone of the Cortina Formation (Kcvsm) will comprise the foundation.

The strike of the bedding is generally north-south with a dip of approximately 50° east. The sandstone and interbedded mudstone are anticipated to be fresh and hard at invert and should provide excellent bearing capacity for the support of the structures. The older alluvium (Qoal) and recent alluvium (Qal) along the alignment for the approach channel ranges in depth from as shallow as 6 feet at the east end of Funks Reservoir to approximately 35 feet at the west end. The soils are primarily lean clay and silt with some gravel interbeds. These soils may be erodible; therefore, the channel would likely require some type of protection.

Only one exploration borehole was drilled at the SPGP site. The rock is approximately 90 percent sandstone (Kcvs) with some minor mudstone interbeds. The sandstone is mostly hard and strong and slightly fractured to massive. The hardness and strength along with the excellent RQD values for the sandstone indicate that, below a depth of approximately 50 feet, blasting will be required. Depth-to-groundwater is approximately 13 feet.

Auger holes were advanced to the top of bedrock along the straight alignment for the approach channel. The current design would encounter approximately 35 to 50 feet of interbedded sandstone and mudstone (Kcvsm). Seismic velocities generated from seismic lines SL-10 and SL-11, in the vicinity of the approach channel, ranged between 8,000 and 9,000 feet per second (fps). Some blasting in the lower 5 to 15 feet of the excavation may be required in the harder, fresh sandstone.

Fault GG-3 trends (approximately N30°E) diagonally across the approach channel approximately 450 feet west of the pumping plant site (Figure 2-12E). Fault trenches excavated by WLA indicate that the “GG-3 fault is a narrow (less than 2 feet wide), sub-vertical bedrock shear zone” (WLA, 2002). GG-3 may act as a groundwater barrier in the bedrock exposed in the approach channel.

Permanent cuts in the alluvial soils should be stable at slopes with a ratio of 2 horizontal to 1 vertical (2H:1V), or possibly at 1.5H:1V slopes upon further investigation and testing. Weathered bedrock slopes should be stable at 1H:1V, and fresh rock slopes at 0.5H:1V along the approach channel. Groundwater would be encountered in the excavation for the approach channel at a depth of approximately 25 feet or higher; therefore, dewatering will be required. Clearing would be minimal at the pumping plant and along the approach channel, as the only vegetation is light grasses and scattered pockets of riparian growth in the Funks Creek channel.

Conveyance Alternatives

Preliminary design of conveyance facilities for the NODOS Project includes the 13-mile Delevan Pipeline from the Sacramento River Pumping/Generating Plant (SRPGP) to Holthouse Reservoir. The pipeline alignment was characterized using a number of auger borings, with SPT, and seismic refraction surveys. Geologic soil units traversed by the proposed conveyance alignment include, from east to west, Sacramento River channel deposits, Modesto Formation, Basin Deposits, Riverbank Formation, Tehama Formation, and Red Bluff Formation. Soils types encountered range from lean clay to poorly graded sand. Cretaceous age mudstone of the Cortina Formation was encountered at relatively shallow depths (16 feet) within the western-most 2 miles of the conveyance alignment. The mudstone was generally decomposed to intensely weathered between 16 and 52 feet, and is considered rippable to that depth. All of the soil units may be excavated using common methods (Figures 2-14A through 2-14C).

Along this 13-mile alignment, groundwater was encountered at relatively shallow depths in all of the auger holes, ranging from 5.5 to 9 feet below the surface. The shallow groundwater depths indicate that dewatering would be required for excavation of most of the conveyance alignment. Temporary slopes for the pipeline excavation in saturated soils should be no steeper than 1.5H:1V, but may require laying back to 2H:1V if instability is a problem.

2.8 Seismicity

2.8.1 General

This section describes faulting and seismicity for the project features under consideration for the proposed NODOS Project. Information is summarized from *Project Geology Report No. 94-30-02*, dated July 2003, *Geologic Feasibility Report, Sites Reservoir Project, Appendix to Engineering Feasibility Report. Project Geology Report No. 94-30-02*, in turn, provided a general summary of the detailed fault and seismic hazard reports prepared by the Division of Planning and Local Assistance, Northern District, Geology Section, and by WLA. Discussions include findings from the 1999 Phase I, Fault and Seismic Hazards Investigation by Northern District, and the Seismotectonic Evaluation, Phase II Fault and Seismic Hazards Investigations conducted by WLA for the NODOS Project. The study also included data from previous mapping and studies conducted by the USGS and Reclamation. The aforementioned detailed geologic reports are referenced at the end of this report.

Analysis of faulting and seismicity data for the two main dam sites (Sites and Golden Gate), the saddle dam sites, and all other project facilities show that displacement along Quaternary-age faults within the reservoir site could be activated by regional seismic sources such as the San Andreas or Great Valley faults.

2.8.2 Faulting

Faults that might have an effect on the proposed reservoir and structures can be categorized into regional and project site faults. Regional faults, such as the San Andreas fault, Cascadia Subduction Zone, and the Great Valley fault (also known as the Coast Ranges-Sierran Block Boundary Zone) are considered active seismic sources for earthquakes that could affect the project area.

The Great Valley thrust fault has been divided into two segments in the area of the project, the Funks Segment and the Bear Valley Segment (Figure 2-15); both segments are blind thrusts with no surface exposure. A seismic event along one or more of the regional faults could result in sympathetic displacement on any of the project site faults.

Figure 2-14A. Exploration and Geologic Map – New Conveyance Alignment

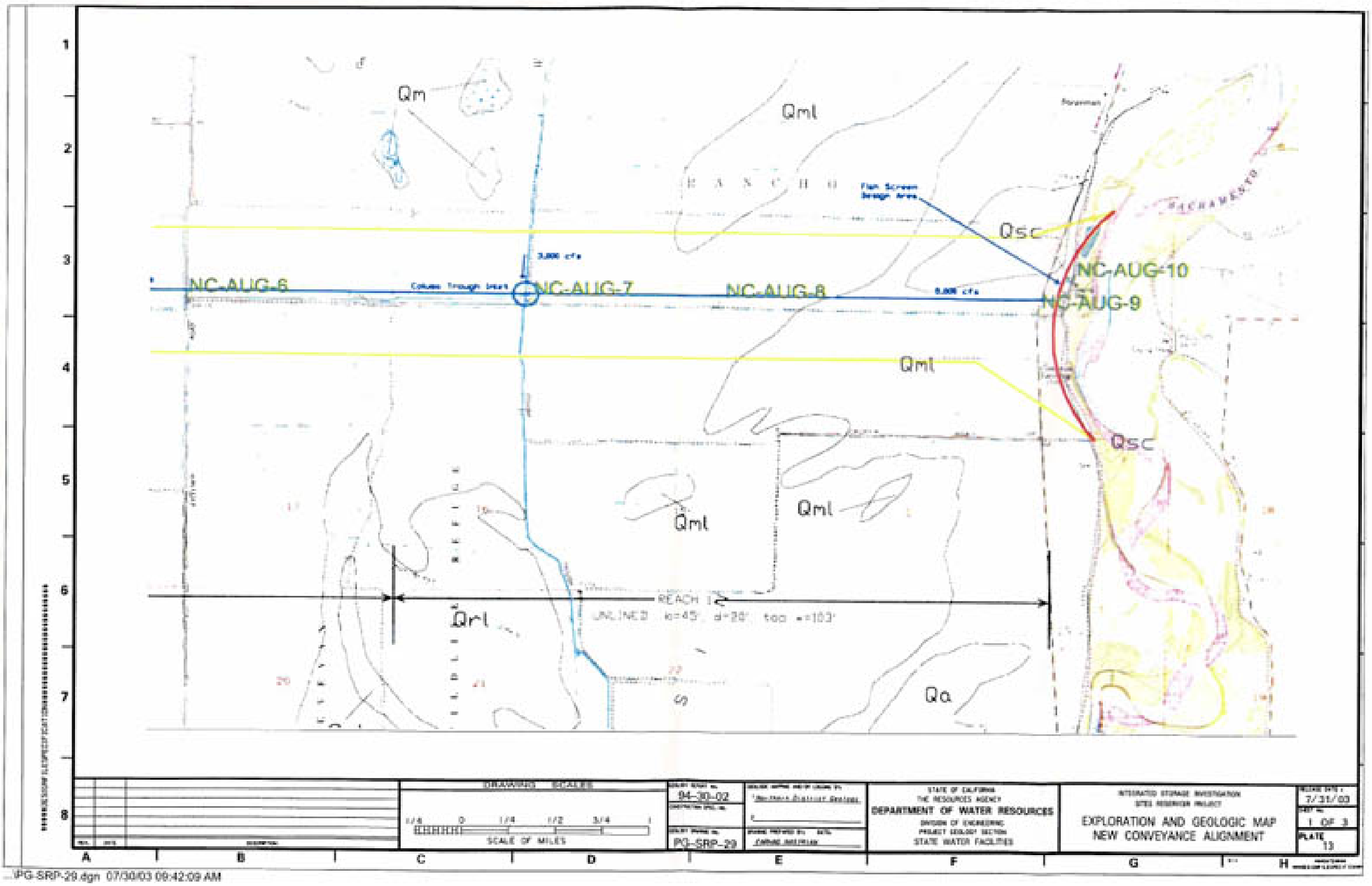

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Figure 2-14B. Exploration and Geologic Map – New Conveyance Alignment

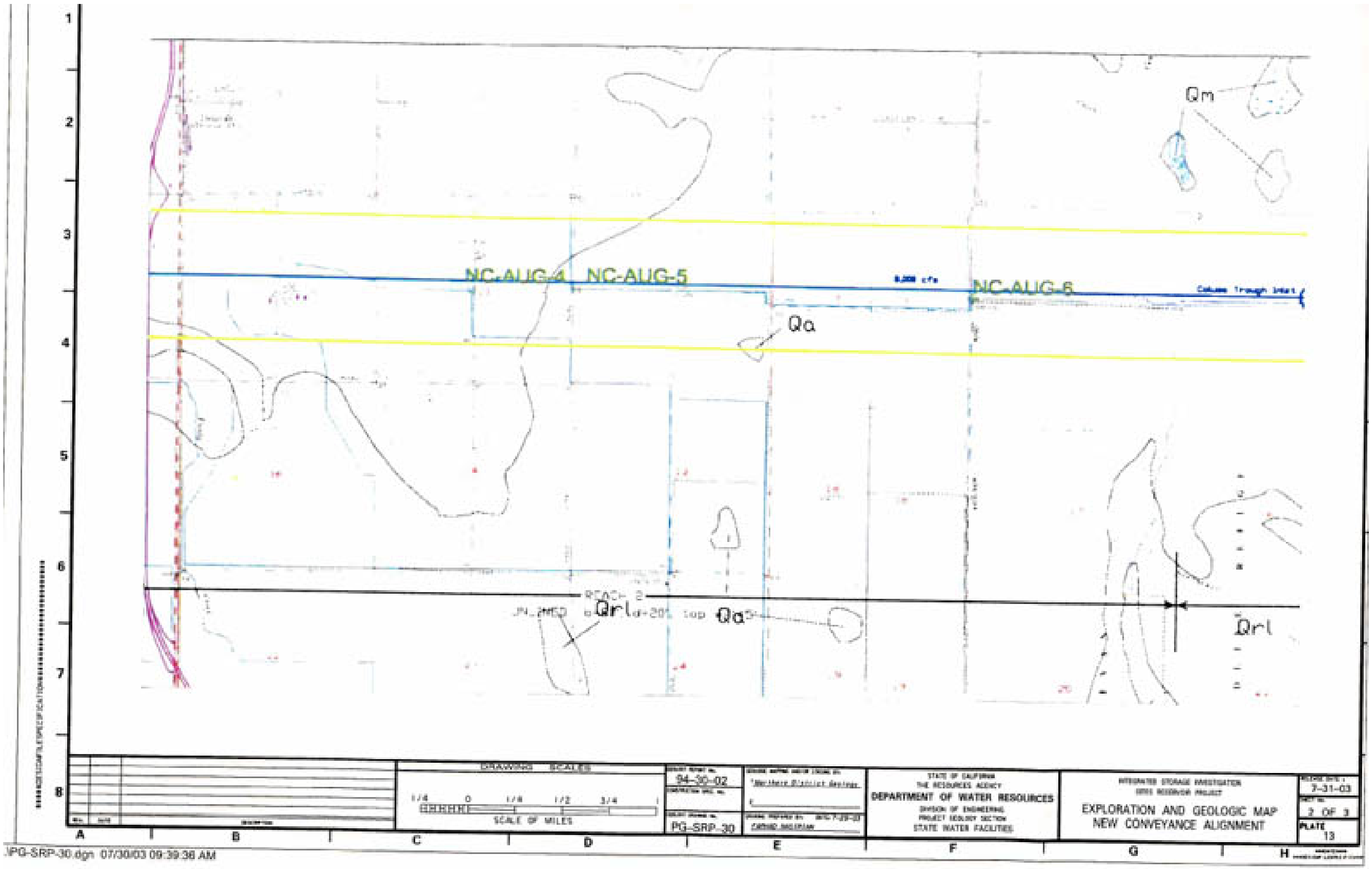

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Figure 2-14C. Exploration and Geologic Map – New Conveyance Alignment Project Area

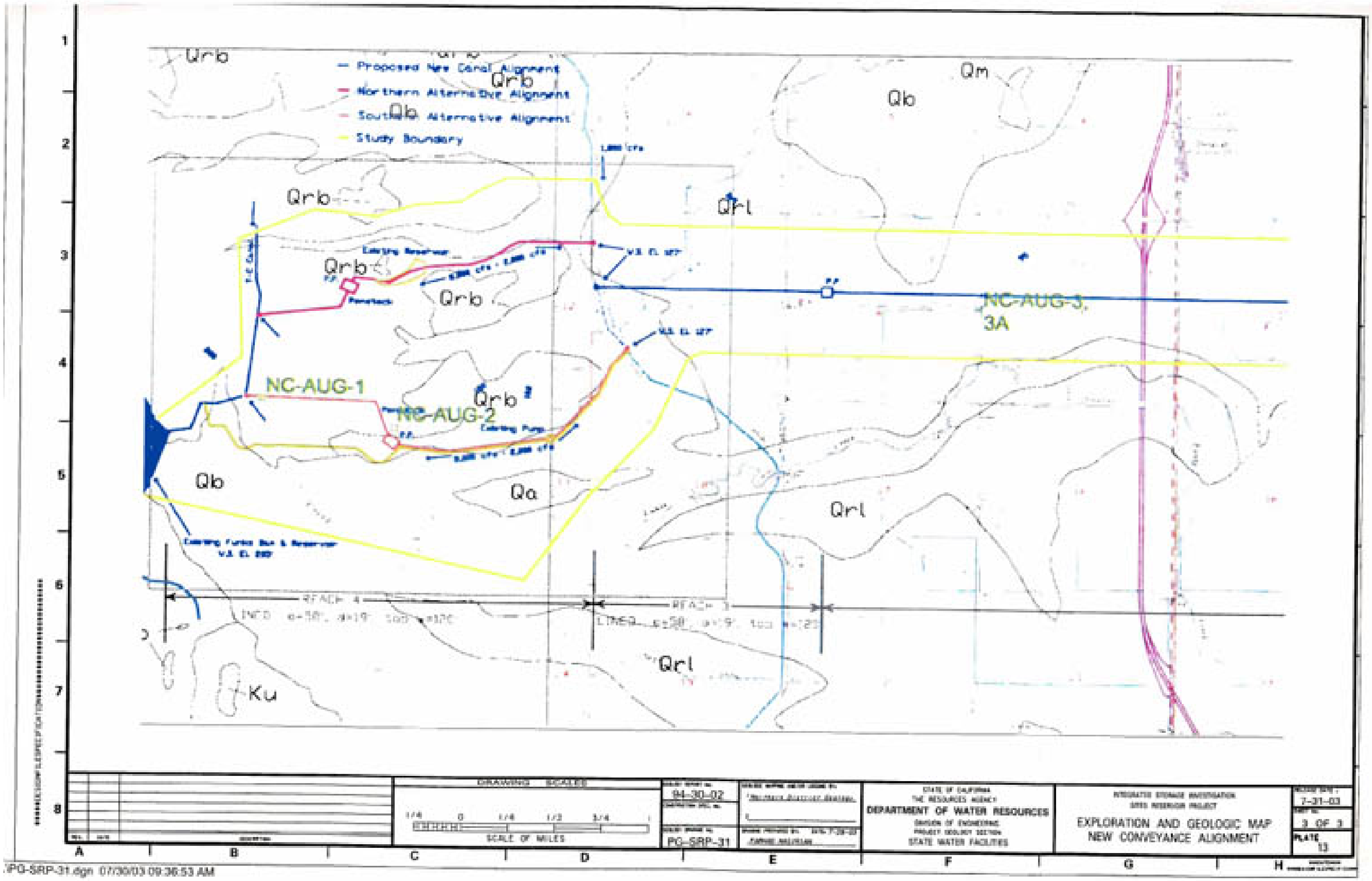

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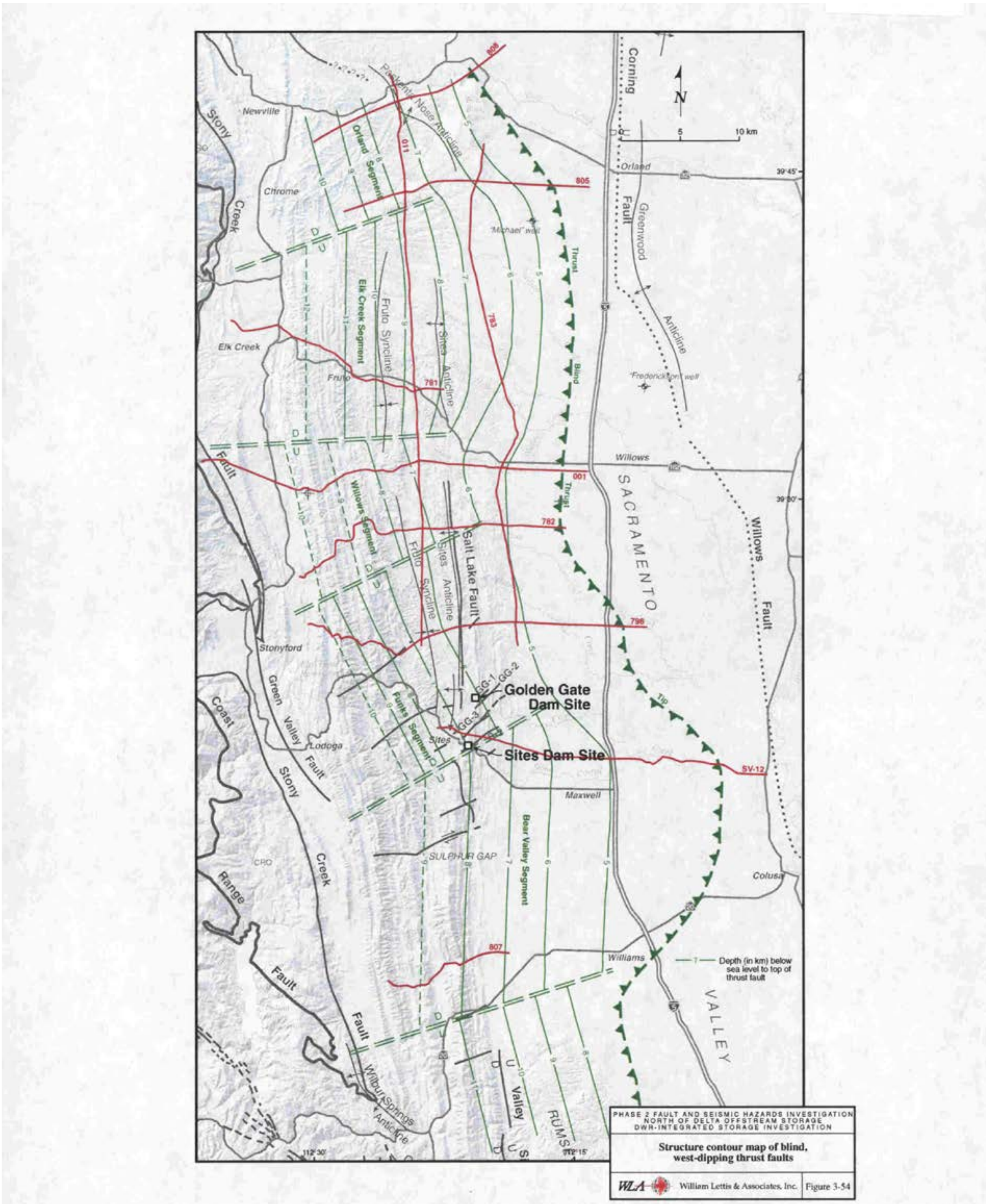
Figure 2-15. Structure Contour Map of Blind West-Dipping Thrust Faults



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Six faults have been mapped within the Sites Reservoir boundaries that could have a significant impact on one or more of the proposed structures (Figures 2-3 and 2-16). Two sets of surface faults have been mapped in the vicinity of the dam sites. The first set is characterized as northeast-striking, high angle faults that obliquely cut the north-striking bedrock units, and consistently displace stratigraphic contacts in a right-lateral strike-slip sense. This fault set includes the informally named S-2, GG-1, GG-2, and GG 3 faults, which traverse through or near the proposed Sites and Golden Gate Dam sites. The second set of faults, characterized as north-striking structures that are generally parallel to bedding, include the east-dipping Salt Lake thrust and S-3 faults. The Salt Lake thrust fault lies within approximately 1 mile of both the Sites and Golden Gate Dam sites, while the S-3 fault has been mapped as passing through the inlet/outlet tunnel immediately west of the pumping plant site. WLA believes that the westward-dipping Funks segment of the Great Valley fault underlies the surface faults and ramps up to and intercepting the Salt Lake thrust fault (Figure 2-17). Faults S-2, GG-1, GG-2, and GG-3 are interpreted as tear faults associated with the Funks segment southern structural boundary.

Exploration trenches have shown that surface rupture may occur along the Salt Lake fault during earthquakes on the Funks segment of the Great Valley fault. The Funks segment is considered the most likely seismic source for the NODOS Project. Studies concluded that approximately 4.5 to 16 inches of reverse displacement might occur during a single surface rupturing event. Paleoseismic data supports only minor movement along the northeast-striking dextral or tear faults GG-1, GG-2, GG-3, and S-2. Analyzing the paleoseismic data with an assumed 3.3 feet of slip and a maximum magnitude earthquake (Mw 6.6) along the Funks Segment, and using three different fault movement models, WLA concluded that displacement along the tear faults would not exceed 8 inches, and is likely be lower (approximately 2.4 to 4 inches).

2.8.3 Seismicity

Historic regional and localized earthquake activity was analyzed by both DWR's Northern District and WLA. The purpose of the earthquake study was to identify potential seismic sources capable of generating significant ground motion at the project site, and to further characterize the seismotectonic setting of the area. Table 2-1 lists potential regional seismic sources and include: the Bartlett Springs, Coast Range, and San Andreas fault zones to the west; the Cascadia subduction zone to the northwest; the Sierra Nevada range to the east; and the Great Valley fault beneath the proposed reservoir site. Moderate to strong earthquakes have been reported in northern California since the mid-1800s. Some of the more prominent events that probably shook the project area include the following: magnitude (M) 6.2 1898 Sonoma County; M 6.5 1898 Mendocino County; M 6.6 1954 Arcata; M 5.7 1940 Chico; M 6 1889 Antioch; three M 5.5 – 6.4 1892 Winters-Vacaville earthquakes; and the M 7.8 1906 San Francisco earthquake on the San Andreas fault zone. The Winters-Vacaville earthquakes of 1892 are of the most importance to this study, as they have been associated with a blind, west-dipping segment of the Great Valley fault (Figures 2-18 through 2-21).

Figure 2-16. Shaded Relief Map Showing Faults in the Vicinity of the Sites and Golden Gate Dam Sites

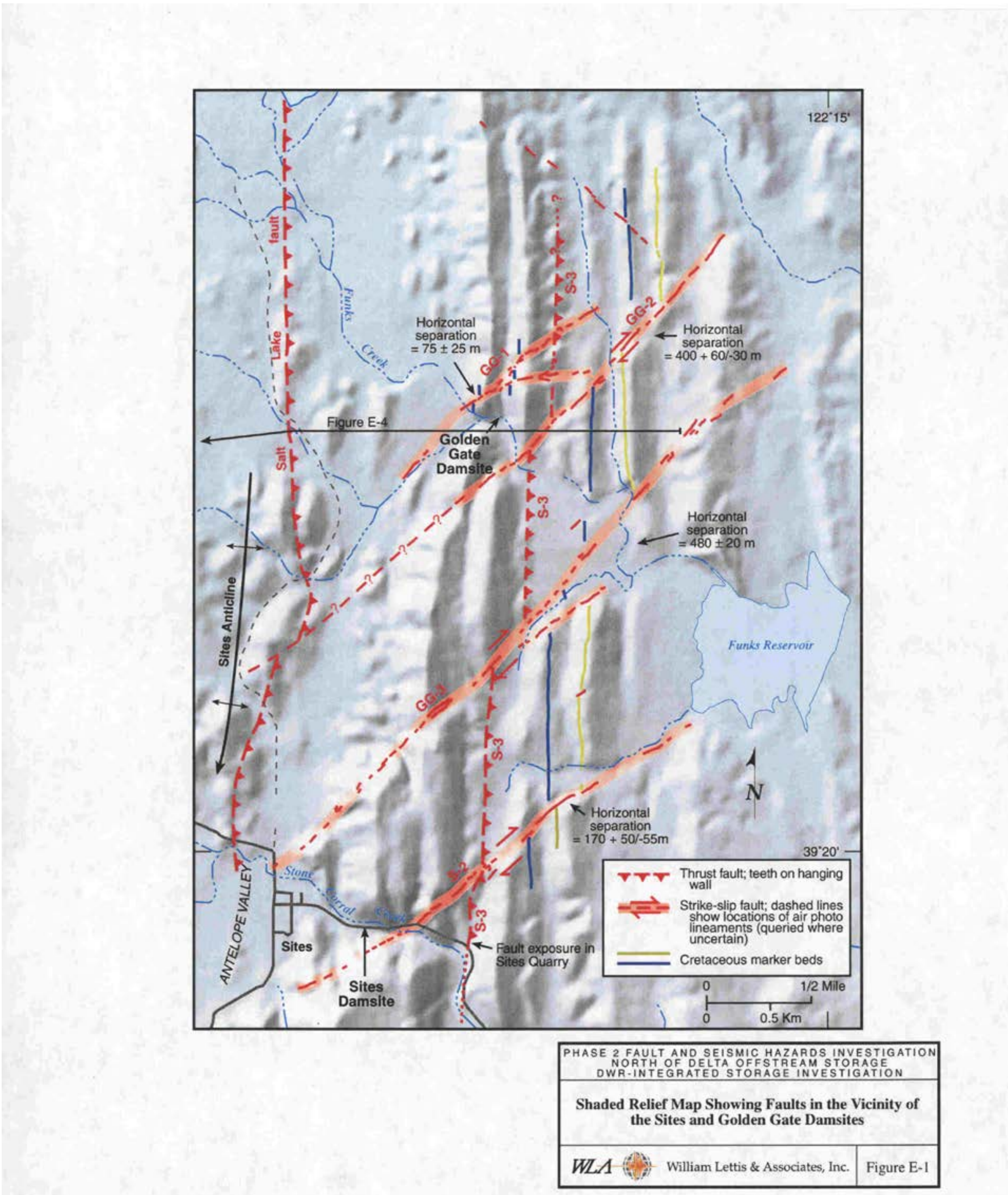

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Figure 2-17. Cross-Section Showing Major Map Scale Structures in the Study Area Reflection Profiles

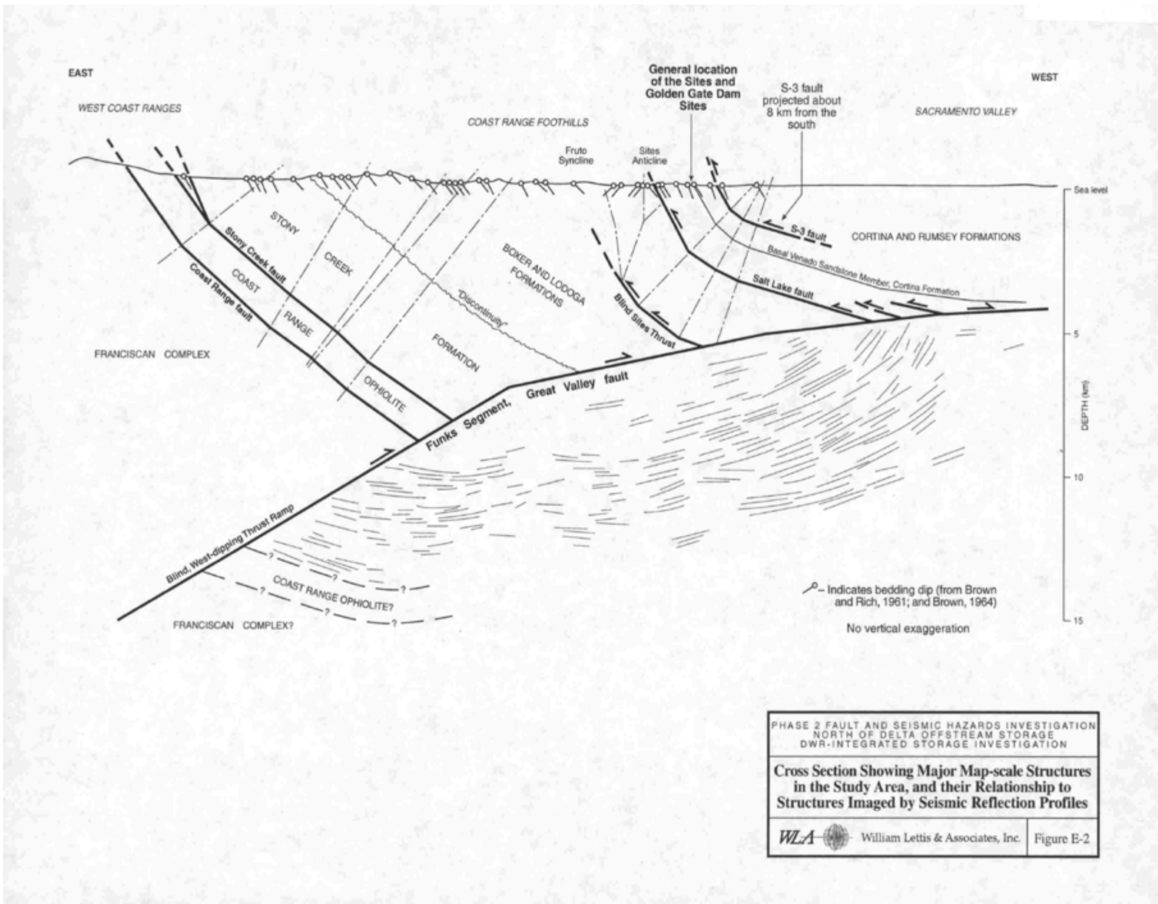

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Table 2-1. Faults and Geologic Structures Investigated in this Report

Fault Name	Fault Type	Activity	Seismic Source Characterization				Closest Approach		Comments
			Fault Length	Fault Width	Rupture Area	Maximum Magnitude	Sites	Golden Gate	
GG-1	Right Lateral, Strike Slip	No Holocene Activity	1.1 mi (1.8 km)	Not a seismic source			3.1 mi (4.1 km)	<0.5 mi (<1 km)	GG-1, GG-2, GG-3 and S-2 are interpreted to be shallow tear faults along Funks/Bear Valley Segment boundary. Conservatively assumed to be sources of aftershocks. Possible surface-rupture hazards.
GG-2	Right Lateral, Strike Slip	No Holocene Activity	3.7 mi (5.9 km)	Faults GG-2, GG-3 are S-2 are considered potential sources of shallow aftershocks. Maximum earthquake magnitude for these structures is M_w 5.4.			1.7 mi (2.3 km)	<0.5 mi (<1 km)	
GG-3	Right Lateral, Strike Slip	No Holocene Activity	3.0 mi (4.8 km)				0.4 mi (0.7 km)	<0.5 mi (<1 km)	
S-2	Right Lateral, Strike Slip	No Holocene Activity	2.4 mi (3.9 km)				<0.5 mi (<1 km)	2.2 mi (3.5 km)	
Salt Lake Fault	Thrust	Multiple Late Quaternary Surface Ruptures	12 mi (20 km)	Not a seismic source			1.5 mi (2.4 km)	1.7 mi (2.7 km)	Interpreted to accommodate triggered, aseismic slip
S-3	Thrust	No Holocene Activity	≥4.25 mi (6 km)	Not a seismic source			0.9 mi (1.5 km)	600 ft (200 m)	May accommodate triggered aseismic slip
Funks Segment, Great Valley Fault	Blind Thrust	Late Quaternary Activity	11 mi (17 km)	14 mi (22 km)	146 mi^2 (374 km^2)	M_w 6.6	4.0 mi (6.5 km)	3.6 mi (5.8 km)	Indirect evidence of late Quaternary activity
Bear Valley Segment, Great Valley Fault	Blind Thrust	Assumed to be Active	14.4 mi (23 km)	14.4 mi (23 km)	207 mi^2 (529 km^2)	M_w 6.8	4.8 mi (7.7 km)	4.4 mi (7.0 km)	Conservatively assumed to be active
San Andreas Fault	Strike Slip	Active	650 mi (1,050 km)	Maximum magnitude = M_w 8 (WLA, 1997)			70 mi (113km)	70 mi (113 km)	Assumes maximum earthquake will rupture 272 mi (435 km)
Maacama Fault	Strike Slip	Active	84 mi (135 km)	Maximum magnitude = M_w 6.5 (WLA, 1997)			45 mi (72 km)	45 mi (72 km)	Too far from sites to dominate hazard
Bartlett Springs Fault	Strike Slip	Active	70 mi (113 km)	9.4 mi (15 km)	117 mi^2 (306 km^2)	M_w 6.6	20 mi (32 km)	22 mi (32 km)	Maximum rupture length of proximal Coyote Rocks Segment is 11 mi (18 km)
Stony Creek Fault	Thrust (?)	Not Active	63 mi (100 km)	Not characterized			10 mi (16 km)	11 mi (18 km)	Interpreted to be a deformed Mesozoic fault

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Table 2-1. (Continued)

Fault Name	Fault Type	Activity	Seismic Source Characterization				Closest Approach		Comments
			Fault Length	Fault Width	Rupture Area	Maximum Magnitude	Sites	Golden Gate	
Coast Range Fault	Normal	Not Active	Not a continuous fault trace	Not characterized			12.4 mi (20 km)	12.4 mi (20 km)	Interpreted to be a deformed Mesozoic fault
Green Valley Thrust Fault and related faults	Thrust	Not Active	11 mi (17 km)	Not characterized			8 mi (12.5 km)	9 mi (15 km)	Bedding-parallel thrust fault confined to the upper 3 mi (5 km) of the crust
Paskenta Fault	Normal	Not Active	28 mi (45 km)	Not characterized			25 mi (41 km)	23 mi (37 km)	Interpreted to be a deformed Mesozoic fault
Rumsey Hills Fault	Blind Thrust	Active	16 mi (25 km)	Not characterized			28 mi (45 km)	30 mi (49 km)	Too far from dam sites to dominate hazard
Sweitzer Fault	Thrust	Active	11 mi (17 km)	Not a seismic source			28 mi (45 km)	30 mi (49 km)	May accommodate triggered aseismic slip
Valley Side Fault	Thrust/Reverse	Active	10.5 mi (17 km)	Not a seismic source			16 mi (26 km)	18.6 mi (30 km)	May accommodate triggered aseismic slip
Black Butte Fault	Bedrock Escarpment	Not a Fault	10.5 mi (17 km)	Not characterized			30 mi (48 km)	27 mi (44 km)	
Southern Reach, Corning Fault	Oblique-Reverse	Active	13 mi (21 km)	13 mi (21 km)	182 mi^2 (462 km^2)	M_w 6.7	20 mi (32 km)	18 mi (29 km)	Associated with clusters of seismicity
Cascadia Subduction Zone	Megathrust Fault	Active	620mi (1,000 km)	74.5 mi (120 km)	46,310 mi^2 (120,000 km^2)	M_w 9	100 mi (160 km)	100 mi (160 km)	Geologic evidence for giant Cascadia earthquakes
Intraplate (Gorda slab) Faults	Probable Strike Slip	Active	Source dimensions not directly observed; maximum magnitude adopted from empirical observations			M_w 7.5	53 mi (85 km)	53 mi (85 km)	1922 Gorda plate earthquake estimated to be M_s 7.6

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Figure 2-18. Historical Seismicity in the Sacramento Valley Region, Pre 1900 - 1969

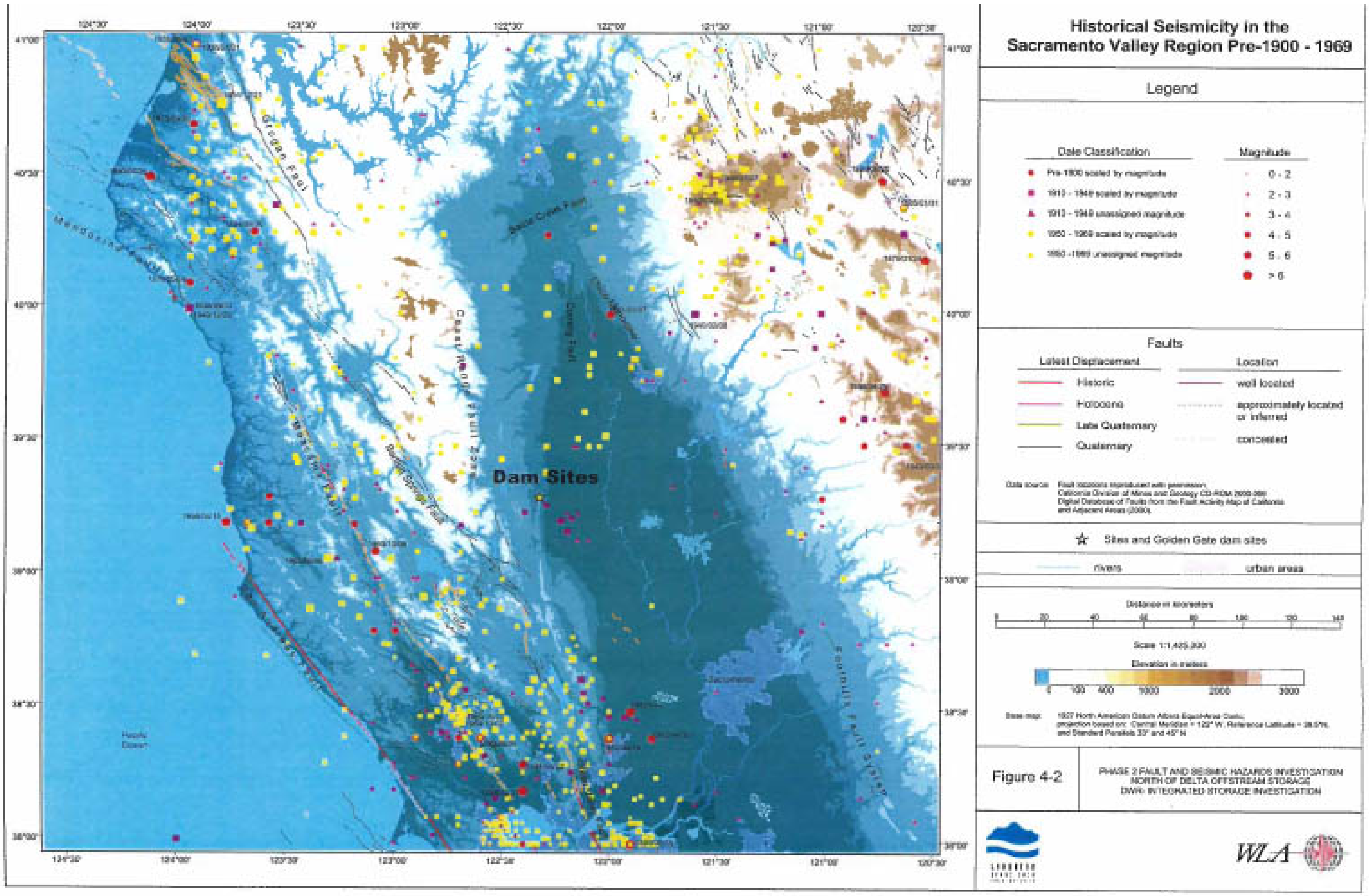

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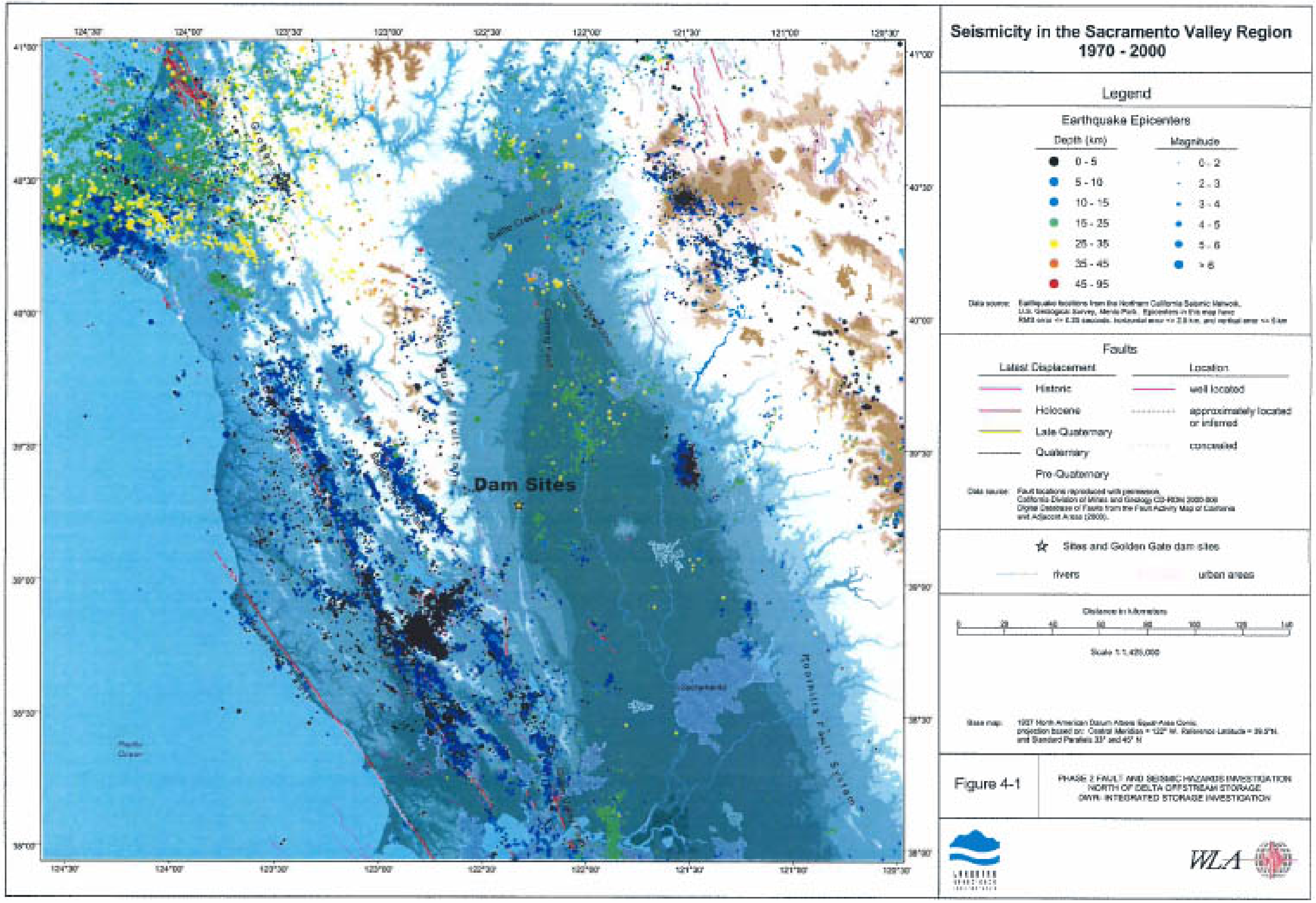
Figure 2-19. Seismicity in the Sacramento Valley Region, 1970 – 2000



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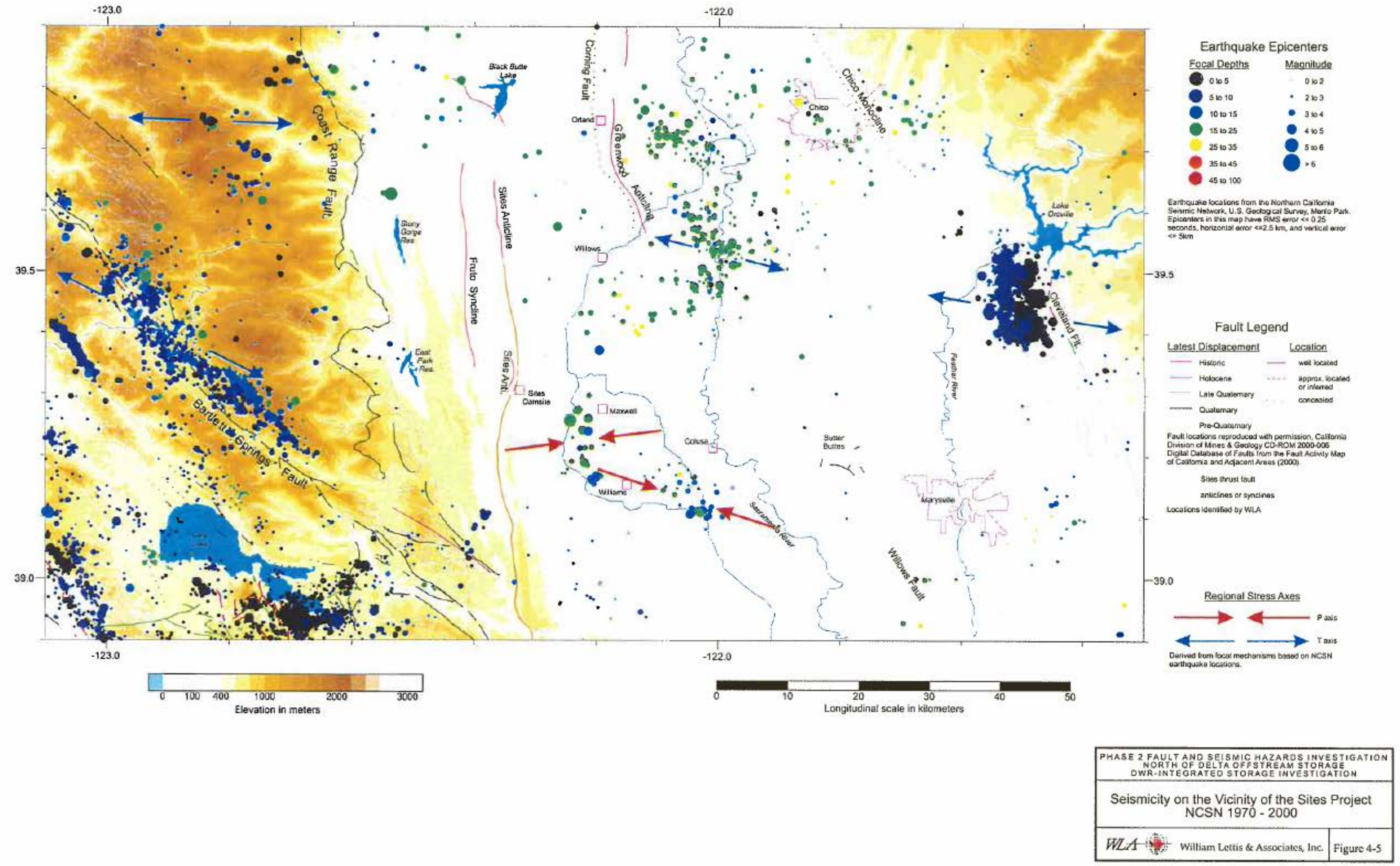
2-20. Seismicity in the Vicinity of the Sites Project – Northern California Seismic Network, 1970 - 2000



Figure

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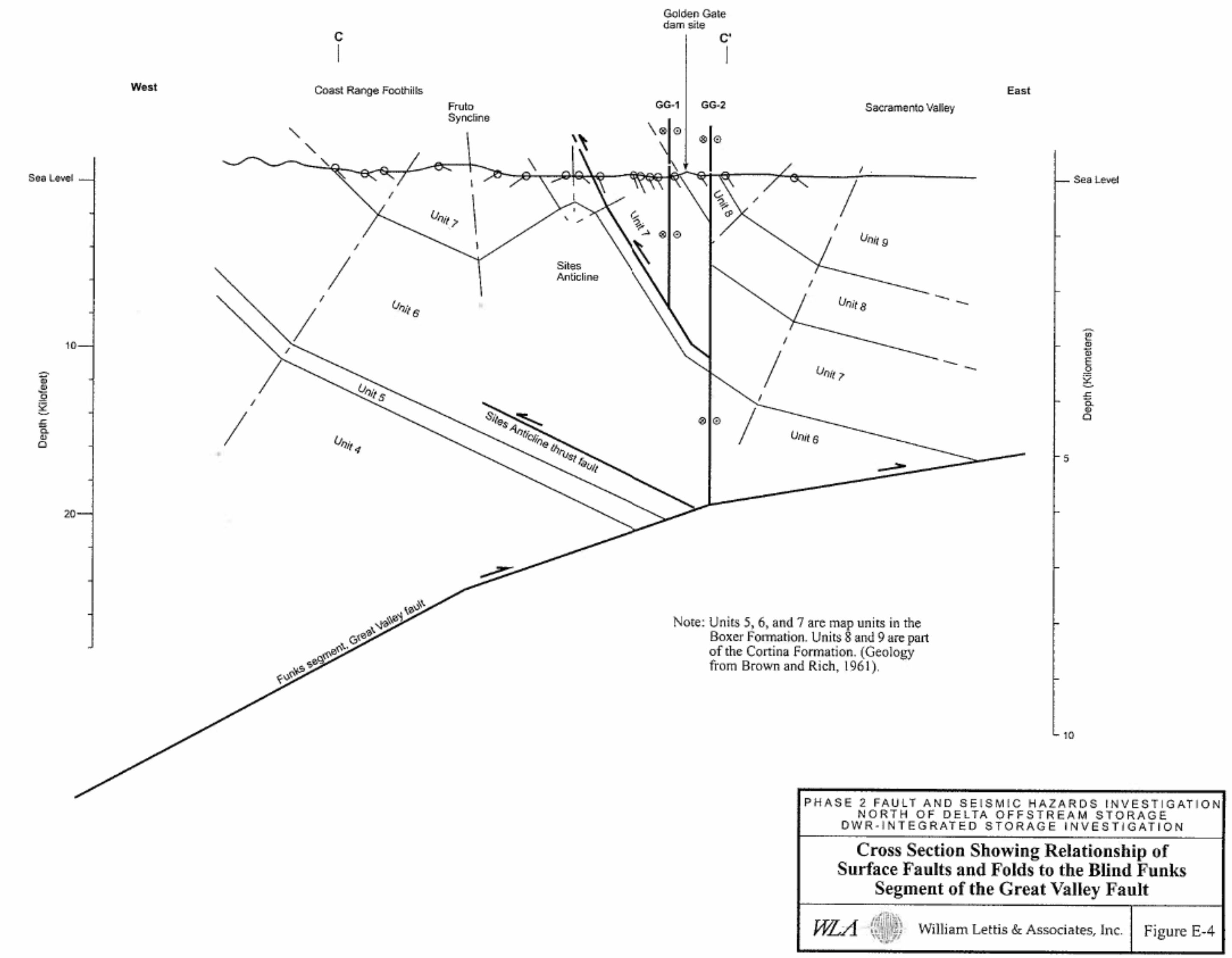
Figure 2-21. Cross-Section Showing Relationship of Surface Faults and Folds to the Blind Funks Segment of the Great Valley Fault



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The Funks and Bear Valley segments of the Great Valley fault are the closest seismogenic faults to the NODOS Project that are considered capable of triggering surface displacement at one or more of the proposed structures. Indirect evidence of late Quaternary activity along the Funks segment includes:

- Paleoseismic trenching studies of the Salt Lake thrust fault have shown that at least one, and probably three or more, surface ruptures have occurred in the past 30,000 to 70,000 years; the Salt Lake thrust fault has been interpreted by WLA as terminating down-dip against the Funks segment of the Great Valley fault.

- Morphometric analysis of regional topography showing evidence of localized late Quaternary uplift coincident with the Sites anticline and Salt Lake thrust fault, both of which are located above the Funks segment.

- Morphometric analysis of stream drainages across Coast Range foothills showing localized fluvial incision and channel morphology consistent with active surface uplift above the Funks segment.

Locally, the northeast-striking tear faults (S-2), GG-1, GG-2, and GG-3 have been interpreted to terminate downward against the Funks segment. It is thought that the tear faults move sympathetically during large magnitude earthquakes on the Funk segment thrust ramp, and do not behave as independent seismic sources. However, WLA has concluded that the northeast-striking faults may be a source of aftershocks following an earthquake on the Funks or Bear Valley segments of the Great Valley fault. Calculations and seismic reflection data analyses by WLA show that the tear faults would have a maximum rupture depth of 3.1 miles, and maximum earthquake magnitudes of Mw 5.3 to 5.4; the rupture depth for GG-1 was calculated at 1 to 2 miles, based on its short surface trace. Maximum surface displacement along the northeast-striking tear faults were calculated to range from 2.4 to 8 inches. WLA's ground motion analysis, using methods by Abrahamson and Silva (1997) and Sadigh et al. (1997), accounting for fault rupture directivity, determined that a peak ground acceleration of 0.8 g (acceleration due to gravity) would be generated from a maximum credible (MCE) of Mw 6.8 on the Bear Valley segment of the Great Valley fault. Analytical results may be slightly less for individual sites and structures within the project area (Figures 2-22 and 2-23).

A similar study was not conducted for the Bear Valley segment of the Great Valley fault south of the reservoir site. However, WLA concluded that the Bear Valley segment is active based on its location within a recognized zone of late Cenozoic tectonic activity and between two other active segments of the Great Valley Fault (Funks segment to the north and the tectonically active Rumsey Hills-Dunnigan Hills region to the south). The Bear Valley segment is considered the controlling seismic source for both major dam sites within the project area, based on comparative earthquake response spectra within a 31-mile radius of the reservoir site. Analyses of surface geologic structures and seismic reflection data indicate that the Bear Valley segment is 14 miles long, 3 to 6 miles deep, strikes north-south, and dips approximately 21º west, has a rupture width of 14 miles, and rupture area of 207 square miles. Further analysis by WLA shows an MCE, or design basis earthquake, magnitude of Mw 6.8 located 4.8 and 4.4 miles, respectively, from the Sites and Golden Gate Dam sites (Figures 2-20 and 2-21).

Figure 2-22. Site-Source Geometry, Bear Valley Segment and Sites Dam Site

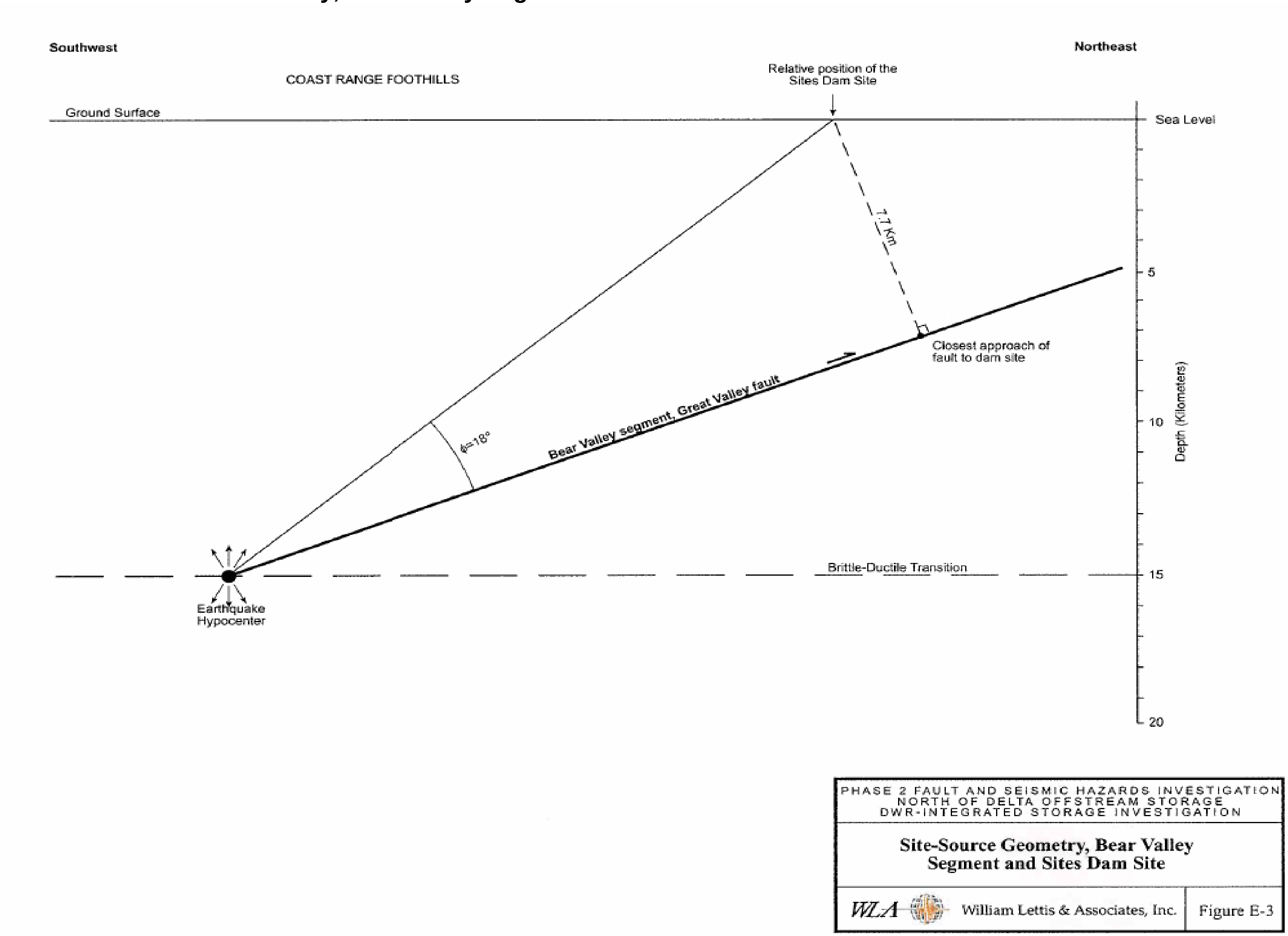

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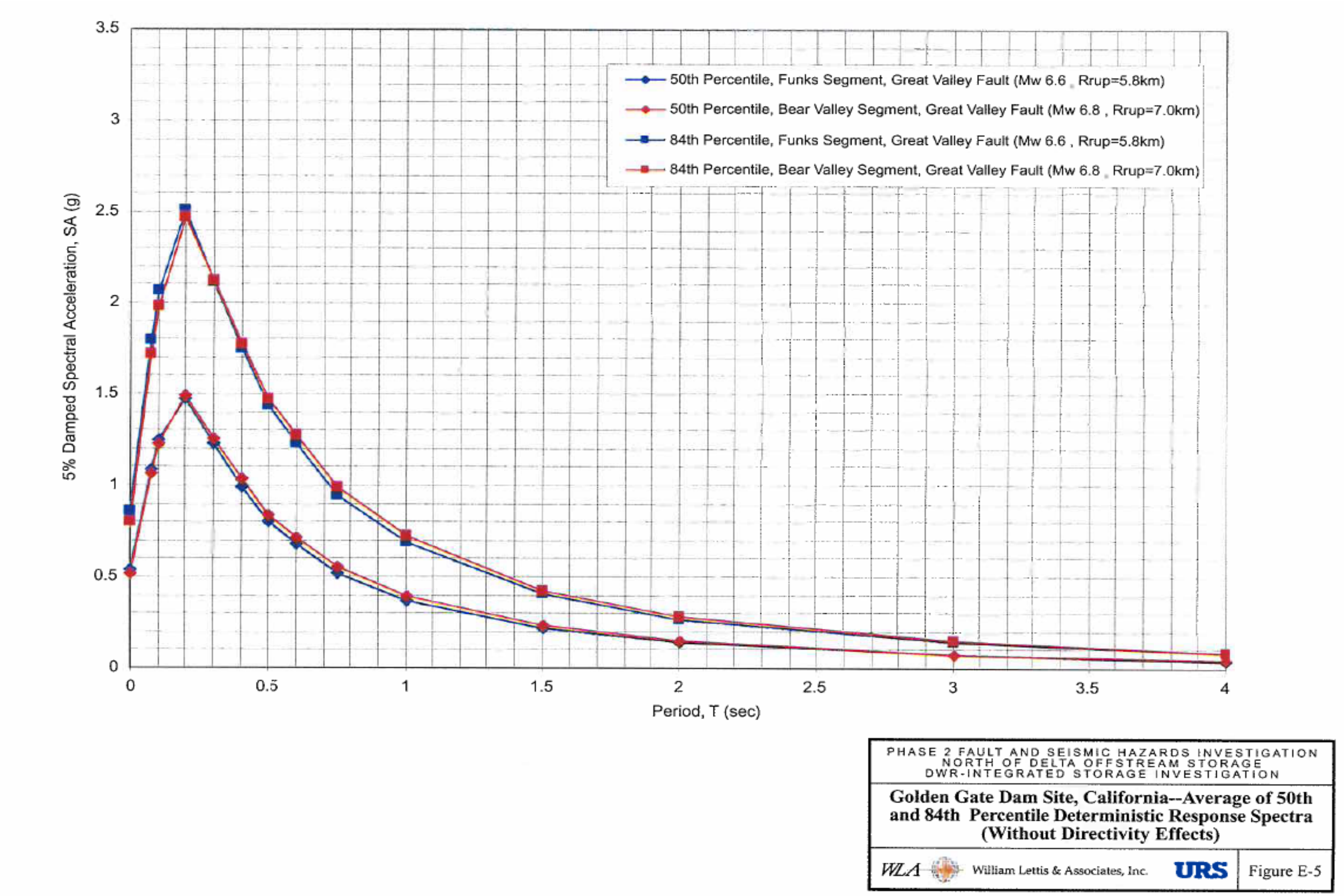
Figure 2-23. Bear Valley and Funks Segments, California – Average of 50th and 84th Percentile Deterministic Response Spectra (without Directivity Effects)



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2.8.4 Reservoir-Triggered Seismicity

Reservoir-triggered (or reservoir-induced) seismicity, which is the triggering of earthquakes by the physical processes associated with the impoundment of reservoirs, is considered hazardous to many large dams. Because of the potential for damage, reservoir-induced seismicity should be considered in the design of most dams.

While reservoir-triggered seismicity has been intensely studied, it is not clear what physical mechanism is responsible for triggering an earthquake, and under what circumstances. A correlation, however, has been observed between dam height and increased seismicity. Two mechanisms are thought to act in triggering fault movement, either in concert or independently. Those mechanisms are a change in crustal elastic stress as the reservoir goes through fill and release cycles, and an increase in fluid pore pressure at the depths that earthquakes originate; the increased pore pressure at depth reduces the effective stress acting on the fault plane.

Earthquakes triggered from reservoir impoundment have been identified both worldwide, and within California. The largest known reservoir-triggered earthquake was a magnitude Mw 6.3, occurring in western India in December 1967. Several possible cases of reservoir-triggered seismicity have been evaluated in northern California. The most prominent of which is the ML 5.7 Oroville earthquake on August 1, 1975, with an epicenter 31 miles east of the Sites Reservoir project.

Given the geologic and tectonic setting of the Sites Reservoir site, the likelihood of reservoir-triggered seismicity is reduced relative to other northern California reservoirs, including Lake Oroville. The general reasons for this are:

- The reservoir site is located within a zone of active compression where the maximum principal stress is expected to be horizontal.

- Bedrock fracture permeability is expected to be less in this region of folding and thrusting, reducing the probability of pore fluid pressure fluctuation.

2.9 Construction Materials

2.9.1 Materials Investigations

Construction materials, for use in embankment dams and levee protection, have been investigated in the NODOS Project area since the 1960s. Previous materials investigations have been performed by the Reclamation and the USACE and were reviewed as part of the current DWR investigation. Reclamation material investigations in 1964 and 1980 included an evaluation of material sources for the construction of dams at the Sites Reservoir site. The USACE investigations focused on evaluating the suitability of Venado sandstone for use as riverbank protection projects on the Sacramento River. The USACE investigations primarily consisted of sampling and testing Venado sandstone at quarry sites downstream of the proposed Sites Dam and were not formally documented in a report. In addition, an extensive evaluation of the shear strength properties of the Venado sandstone is presented in a University of California, Berkeley report published by Becker et al. in 1972.

Because material requirements for the Sites Reservoir dams constitute a major component of the overall NODOS Project, the primary focus of the preliminary materials investigation program was to identify and evaluate materials sources for construction of the proposed dams. The current DWR construction materials investigation program consisted of an assessment of available on-site and off-site material sources, laboratory testing, and an evaluation of the suitability and engineering properties of the available materials. The assessment included a review of published data, field investigations, and material sampling with materials testing performed at DWR's Soils and Concrete Laboratory. An evaluation of the engineering properties and suitability of the available materials for construction of the proposed dams is documented in the report *North-of-the-Delta Offstream Storage Investigation, Sites Reservoir Feasibility Study, Materials Investigation, Testing, and Evaluation Program* (DWR, 2002).

2.9.2 Material Sources

General

The construction materials investigation program examined the following materials available in or near the proposed Sites Reservoir project area: alluvial deposits (Recent and older alluvium), and Venado sandstone of the Cortina Formation (fresh and weathered).

Mudstone of the Boxer Formation

These material sources were investigated, tested, and evaluated to examine their suitability for use as the following types of construction materials: impervious core; rockfill and riprap; random fill; filter, drain, and transition; and concrete aggregate.

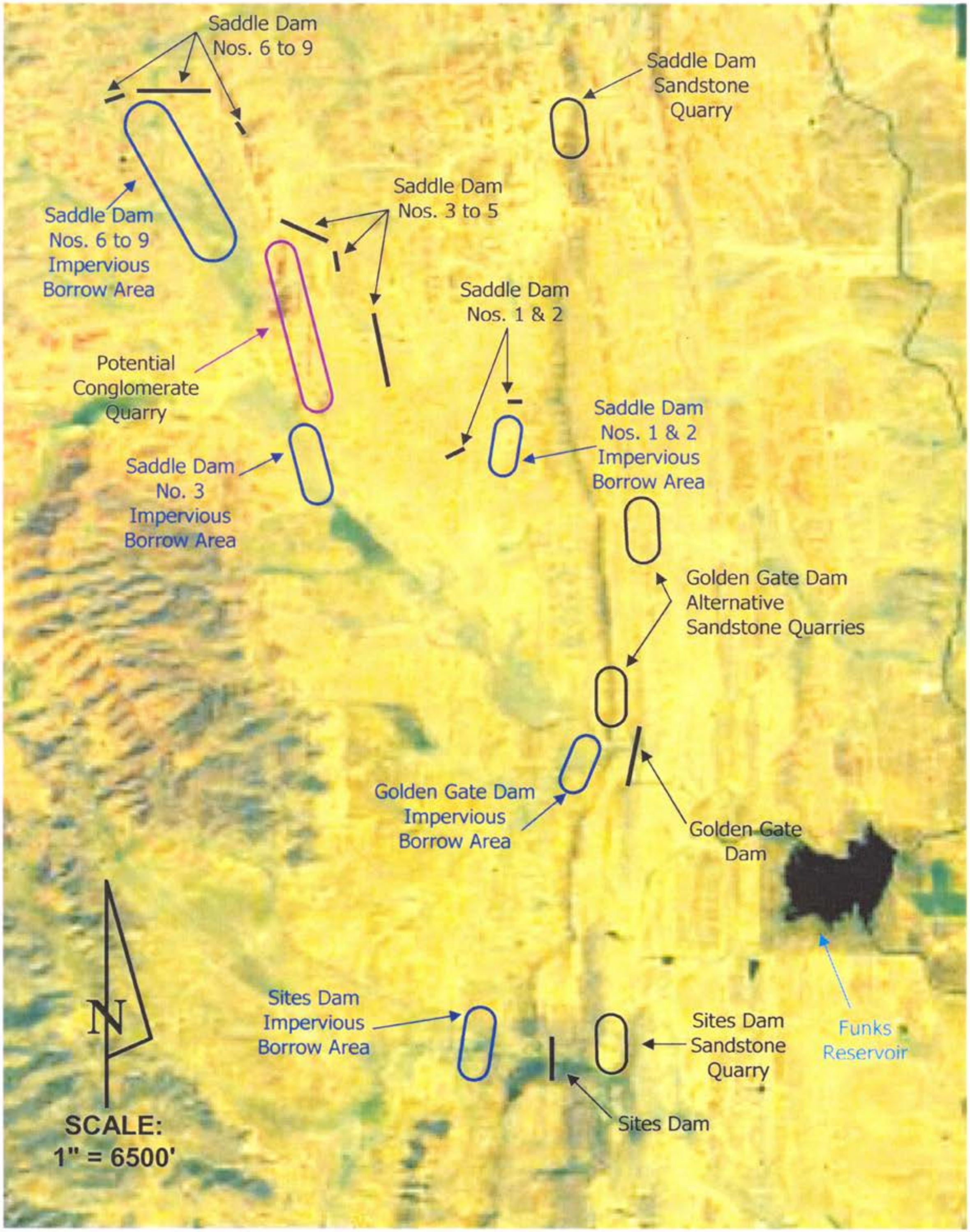
Impervious Core

A large amount of potential impervious material exists within or near the Sites Reservoir project. Previous studies by Reclamation identified four main areas of alluvial deposits in the reservoir area encompassing roughly 36 million cubic yards of material. Figure 2-24 illustrates the extent of these deposits. Additional impervious materials are located within required excavation areas for the appurtenant structures and Funks Reservoir enlargement. These required excavation areas would be utilized to the maximum extent practicable. Additional quantities of impervious materials are located in potential borrow sites located within 1 mile of each of the 11 dam sites. Figure 2-24 illustrates the locations of these potential borrow areas. The impervious materials are suitable for use in the proposed embankment dams, and are generally classified as low to medium plasticity clays, with lesser amounts of high plasticity clays, and clayey sands.

Rockfill and Riprap

The best available source of clean rockfill material within the project area is fresh Venado sandstone. Sandstone quarry areas have been identified within 1 mile of both the Golden Gate and Sites Dam sites, and are presented in plan view in Figure 2-24. Sufficient quantities of fresh sandstone for rockfill material can be obtained from these quarries to construct the proposed embankment dams.

Figure 2-24. Sites Reservoir – Proposed Impervious Borrow Areas and Quarries



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Future design investigations should also evaluate the advantages and disadvantages of developing one centrally located quarry for both Golden Gate and Sites Dams instead of developing a quarry for each dam.

Figure 2-24 also presents a proposed sandstone quarry location for construction of the saddle dams. The haul distance from this proposed quarry is roughly 3 to 4 miles from the saddle dam sites. A potential alternate source of rockfill and riprap material for construction of the saddle dams is a ridge of conglomerate located within the reservoir area near Saddle Dam 3 (Figure 2-24). Although not evaluated as part of the materials investigation program, this potential rockfill source offers a shorter haul distance to the saddle dams (1 to 2 miles). This rockfill source would cause less environmental impacts in comparison to the proposed sandstone quarry, because the ridge of conglomerate is located within the reservoir area and the potential sandstone quarry is not. Because the suitability of the conglomerate cannot be confirmed at this time, it was assumed that development of the sandstone quarry would be required for construction of the saddle dams.

Random

It is anticipated that two general types of random materials would be generated during construction depending upon the source of the material. One type of random material would be comprised of predominately weathered sandstone from the Cortina Formation, while the other type would be predominately mudstone from the Boxer Formation. Mudstone from the Boxer Formation would tend to be “soil like” after excavation and compaction operations, as it is a low-strength rock and has a propensity to break down when exposed to air and water. The weathered Cortina Formation would tend to be a dirty rockfill.

At the Sites and Golden Gate Dam sites, random embankment material would be comprised of materials unsuitable for use as clean rockfill. Materials would consist of weathered sandstone, mudstone, slopewash, etc., from excavations for the dam foundations, appurtenant structures, and rockfill quarries. Material from clearing and grubbing operations would not be used in any embankment structure. Random material generated during construction of these dams would have haul distances of less than 1 mile.

Random material would be generated from the Boxer Formation during construction of the saddle dams and designated borrow areas. Random material borrow areas for construction of the saddle dams have not been identified, but would be located within the reservoir area with haul distances of less than 1 mile. Sufficient quantities are available for construction of the saddle dams. Although the Boxer Formation material would function more as an upstream and downstream shell zone in the saddle dam sections, the term “random” is used for this material zone to be consistent with the terminology used at Sites and Golden Gate Dams.

Filter, Drain, and Transition Materials

Deposits of sand and gravel of sufficient quantity for construction of the Sites Reservoir dams are not available in the project area. Therefore, alternative sources of filter, drain, and transition materials were examined as part of the preliminary materials investigation. Laboratory testing indicated that crushed, fresh Venado sandstone may be suitable as filter, drain, and transition materials. However, it was not extensively tested as part of the materials investigation because a particle breakage evaluation would have been required. This particle breakage evaluation will require test quarries and fills and was considered beyond the scope of the preliminary investigations. Because the suitability of the Venado sandstone cannot be confirmed at this time, it was assumed that filter, drain, and transition materials for the proposed embankment dams would be imported from the closest off-site sand and gravel deposit. This off-site deposit was identified as an old channel on Stony Creek, between Orland and Willows (Figure 2-25). The channel is approximately 30 to 35 road miles from the project area, and has an estimated material availability of 160 million cubic yards, far exceeding the construction requirement.

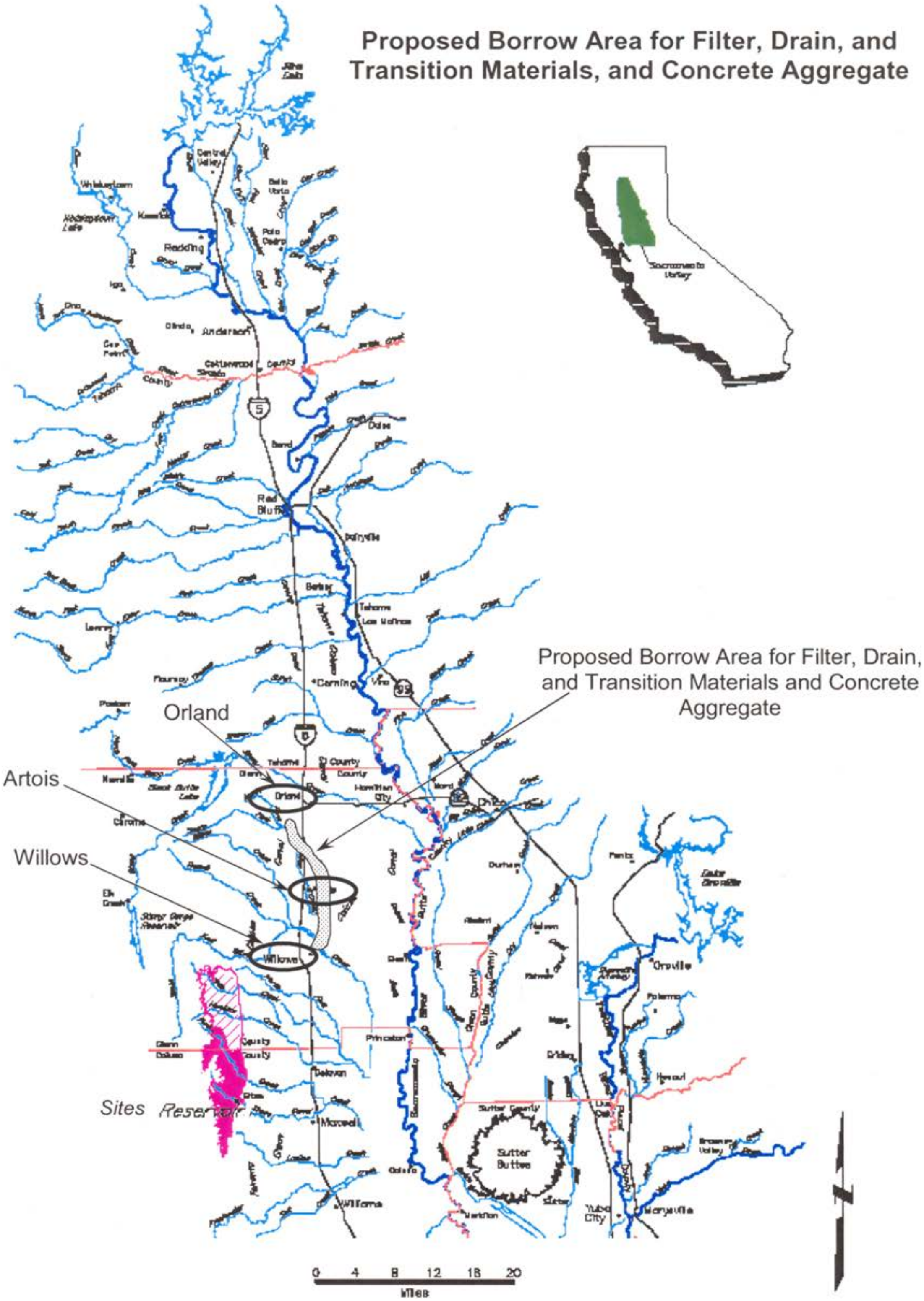
Concrete Aggregate

Similar to the approach used for filter, drain, and transition materials, crushed Venado sandstone and off-site sand and gravel deposits were examined as potential sources of concrete aggregate. Preliminary testing performed on crushed samples of Venado sandstone indicates that it marginally meets concrete aggregate suitability criteria. Verification of the suitability of the Venado sandstone for use as concrete aggregate would be the focus of future investigations.

Construction Water

Construction water would be obtained from Funks Creek and Stone Corral Creek. Additional water would be supplied by off-site sources if required.

Figure 2-25. Proposed Borrow Area for Filter, Drain, and Transition Materials, and Concrete Aggregate



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